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MANUFACTURING TECHNOLOGY FOR HIGH VOLTAGE POWER SUPPLIES (HVPS)

Volume III - Procedural Details

Northrop Grumman Corporation
Electronics and Systems Integration Division
600 Hicks Road
Rolling Meadows IL 60008

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This technical report has been reviewed and is approved for publication.

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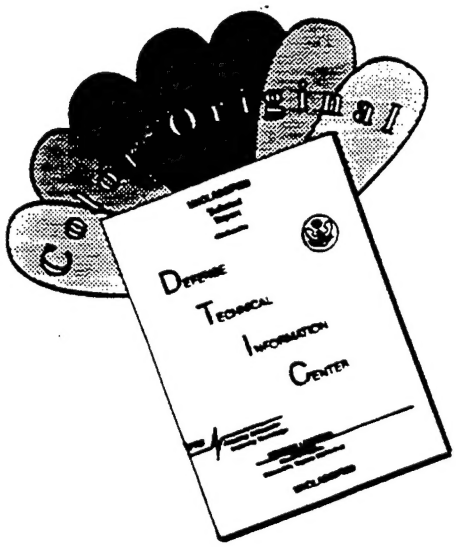

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13. ABSTRACT

This report is the culmination of a multi-year manufacturing technology program sponsored by the Electronics Division of Wright Laboratory Manufacturing Technology Directorate (WL/MTM). The program was jointly conducted by Northrop Grumman Electronics and Integration Division as the prime contractor and Hughes Aircraft Company Technology Support Division as the principal subcontractor. The thrust of this program was to improve the reliability of High Voltage Power Supplies (HVPS). This was accomplished by conducting a comprehensive evaluation of the materials, components and processes used to produce HVPS. To demonstrate the benefits of the program the lessons learned were incorporated into two existing HVPS, ALQ-135 and AMRAAM. Several of these upgraded high voltage assemblies were fabricated and tested to measure the benefits resulting from the changes. The report is published in four volumes. The first volume is a summary of the technical activity and highlights of the program. The remaining three volumes provide the specific program and procedural details and reference information generated in performance of the effort. This report, Volume III - Procedural Details, contains procedures on how to perform the various component, material and process evaluations, and gives results obtained from the Northrop Grumman/Hughes Aircraft Company efforts. The Volume III procedures are basically stand alone documents and have been numbered as such. They can be referenced for specific areas of interest or treatment of problems; however, when reference is made to Model Test Structures, Volume IV should be viewed for specific construction details.

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DESIGN AND MANUFACTURING GUIDELINES FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

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GENERAL INTRODUCTION

The Guidelines contained here-in are presented in four volumes:

Volume 1, Design and Manufacturing Guidelines for High Voltage Power Supply, Program Summary.

Volume 2, Program Details, gives introductory and background information, the approach used, design/development considerations and general information for use by High Voltage Power Supply designers and manufacturers.

Volume 3, Procedural Details, contains procedures on how to perform the various component, material and process evaluations, and gives results obtained from the Northrop Grumman/ Hughes Aircraft Company efforts. The volume 3 procedures are basically stand alone documents and have been numbered as such. They can be referenced for specific areas of interest or treatment of problems; however, when reference is made to Model Test Structures, Volume 3 should be viewed for specific construction details.

Volume 4, Reference Information, contains specific construction details on Model Test Structures used throughout the program as well as test results obtained from the various material and component studies.

The information developed in these four volumes is the result of a joint Northrop Grumman Electronics Systems and Hughes Electro-Optical Systems effort initially begun in mid-1990. The initiative and primary funding for this effort was provided by Wright-Patterson AFB, Wright Labs ManTech Directorate, project manager M. Price. Supplemental funding from internal R & D funds was also provided by Northrop Grumman. General Research Corporation (J. Basine, K. Dunker) and consultant, W. Dunbar, served as contract monitors during the course of the program.

Note: Because the information presented is from research provided by multiple sources within each of the two contractors (as well as numerous third party sources), the writing styles, formatting and print emphasis vary somewhat. This should not detract from the content in any way.

Most of the test procedures in this volume refer to very specific test equipment and test techniques. The HVPS practitioner should also consider these documents in a generic sense (using "like equipment for example") as an option to perform the evaluations. Furthermore, experience indicates that allowing time for developing and debugging these procedures, if the evaluations are to duplicated, is a must consideration to insure repeatable, consistant results over time.

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

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1.0 Components	
1.1 Corona Test Procedure	1.1-1 to 1.1-15

1.1 Corona Test Procedure

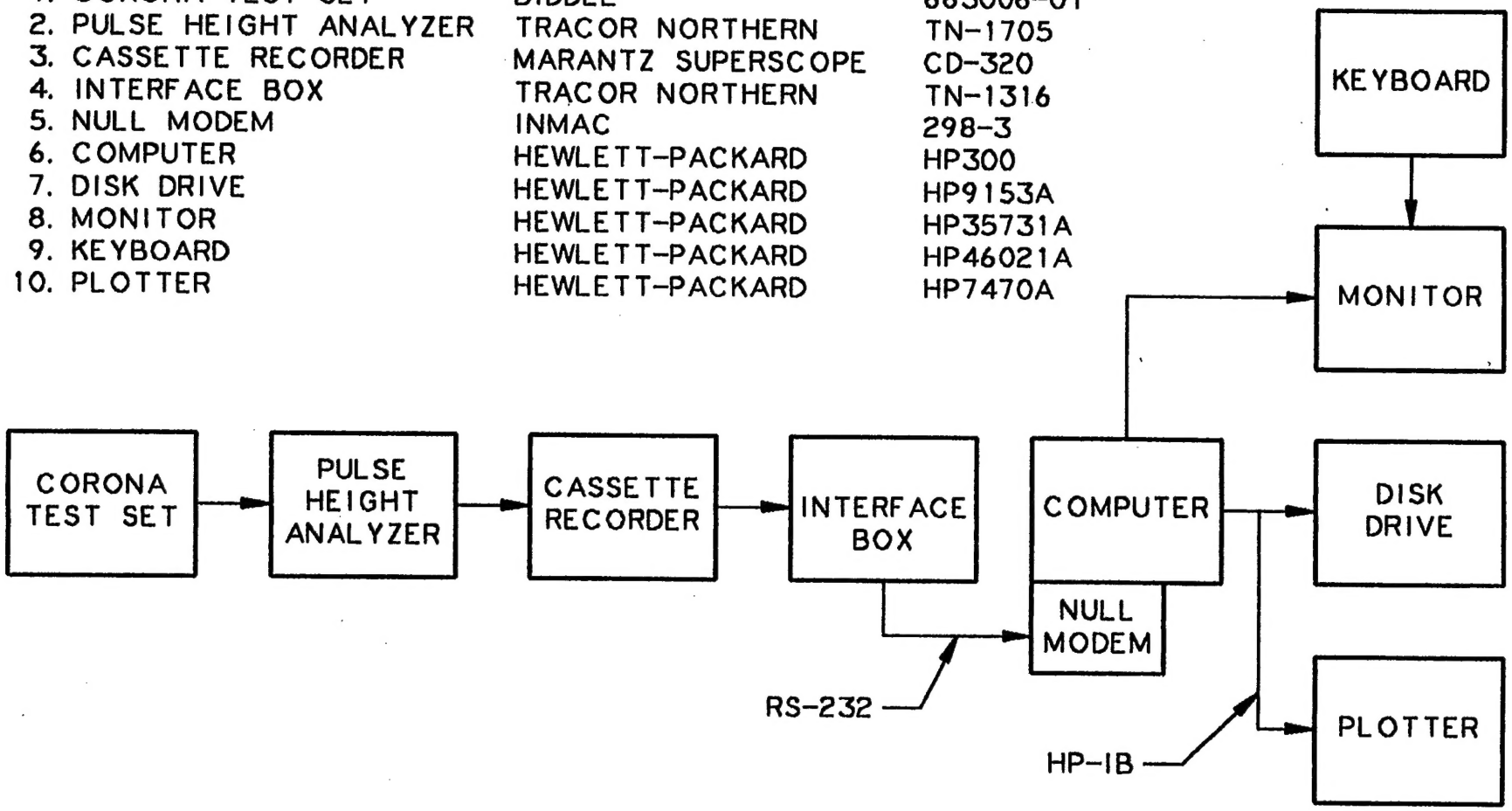
The procedure that follows identifies specific equipment and gives detail "how to" information for measuring and recording corona and breakdown voltage.

For the AC corona determinations, observations of both corona inception voltage (CIV) and corona extinction voltage (CEV) were made. In these determinations, corona inception was identified as the voltage level resulting in discharges equal to or greater than 1.0 picocoulomb. Corona extinction was the voltage at which the discharge became less than 1.0 picocolumb, or disappear entirely.

All DC corona determinations were performed by raising the voltage to a predetermined level and monitoring for the occurences of corona discharges for a defined charge accumulation period. The results are then presented in terms of the total discharge for the measurement period. Selection of the predetermined voltage level is based on both observation of discharge activity as the voltge is step increased, and in later testing in a predetermined maximum DC stress level. The maximum stress level was used to permit observations of changes in the DC corona charater without a high risk of destroying the Unit Under Test (UUT) via electrical breakdown. Typical operating level was 8.0 Kv for 60 seconds. UUTs not experiencing catastrophic breakdown were considered to PASS the DC test.

EQUIPMENT LIST FOR CORONA MEASUREMENT PROCEDURE

DECRIPTION	MANUFACTURER	MODEL
1. CORONA TEST SET	BIDDLE	663006-01
2. PULSE HEIGHT ANALYZER	TRACOR NORTHERN	TN-1705
3. CASSETTE RECORDER	MARANTZ SUPERSCOPE	CD-320
4. INTERFACE BOX	TRACOR NORTHERN	TN-1316
5. NULL MODEM	INMAC	298-3
6. COMPUTER	HEWLETT-PACKARD	HP300
7. DISK DRIVE	HEWLETT-PACKARD	HP9153A
8. MONITOR	HEWLETT-PACKARD	HP35731A
9. KEYBOARD	HEWLETT-PACKARD	HP46021A
10. PLOTTER	HEWLETT-PACKARD	HP7470A



BLOCK DIAGRAM FOR CORONA MEASUREMENT PROCEDURE

CORONA MEASUREMENT PROCEDURE

1.0 EQUIPMENT SETUP

1.1 Biddle Corona Test Set

CAUTION!

Operation of this test set involves high voltage that is hazardous and can be lethal to operating personnel. The normal precautions of working with high voltage must be exercised by all persons involved in the operations and tests. Use of a grounding stick is recommended to assure discharge of all high voltages before handling any of the high voltage connections.

1.1.1 Assure the ac and dc high voltage power supply controls are set for zero and that the supplies have been checked for discharge with the grounding stick.

1.1.2 Make the required connections in the high voltage power supply cabinet (lower door) as shown in the photographs accompanying the Instruction Manual. There is a photograph for each of the three most used supply connections:

a. DC Bus Setup (DC voltage only)
b. AC Bus Setup (AC voltage only)
c. Superimposed Bus Setup (AC voltage superimposed on DC voltage)

1.1.3 The unit under test (UUT) will be placed in the high voltage test cabinet (upper door) and should be sufficiently isolated from the cabinet walls and floor. A container of dielectric fluid (typically FC-40) will be required for immersion of the UUT and all exposed high voltage connections for most tests. NOTE: Masking of a possible problem in the UUT may occur due to immersion in and possible impregnation by the dielectric fluid.

1.1.4 The lead wire to connect the high voltage output of the Power Separation Filter to the UUT must be of good high voltage quality and should be held away from the cabinet walls and floor during the tests.

1.2 Pulse Height Analyzer

1.2.1 Use a BNC cable to connect the AUX AMP OUT connector on the left outside wall of the Corona Test Set to the INPUT connector on the front panel of the Pulse Height Analyzer (PHA).

1.2.2 Connect the four-cable I/O harness from the front panel of the PHA to the connectors on the right side of the Cassette Recorder. Follow the painted-on color code for the cable connections to the Cassette Recorder - blue to LINE IN LEFT, green to LINE IN RIGHT, red and yellow have no connection.

1.2.3 Set the front panel controls of the PHA as listed below:

a. POWER to ON.
b. GAIN to 0.
c. LLD to 0.1 typical but may be different as determined in the Background Test in paragraph 3.0.
d. ULD to 10.0 (maximum CW).
e. OFFSET to 0.
f. MODE to PHA.
g. CONVERSION GAIN to 1024.
h. PRESET to LIVE.
i. TIMEBASE to 6 and 10 (PHA).
j. HORIZONTAL to 1/2 or 2/2 as required.
k. VERTICAL SCALE to 100 or as required.
l. EXPAND and POSITION as required to place the horizontal trace in the desired location.
m. CURSOR as required.
n. AMP to OUT
o. ADD/SUB to ADD.
p. I/O to ALL OUT.

1.3 Cassette Recorder

1.3.1 Install a cartridge in the Cassette Recorder and depress REC and PLAY. At some distance into the tape depress PAUSE.

1.3.2 Set the other controls on the recorder as listed below:

a. TONE and VOL to near minimum CCW.
b. DOLBY NR to ON.
c. EQ to 70uS.
d. BIAS to LOW.
e. REC SELECT to MANUAL.
f. Adjust REC LEVEL LEFT to 6 and RIGHT to 7 as indicated on the respective VU meter.

1.4 Interface Box

1.4.1 Connect the cable labeled LINE OUT from the RECORDER connector on the Interface Box to the LINE OUT R jack on the recorder. The other cable in this harness has no connection.

1.4.2 Connect the EIA connector on the Interface Box to the RS-232 connector on the HP300 Computer. This connection must be made through a Null Modem.

1.4.3 Set the ac switch to ON on the Interface Box.

1.5 Computer and Peripherals

1.5.1 Use a normal interconnection scheme between the HP300 Computer, HP9153A Disk Drive, HP35731A Monitor, HP 46021A Keyboard and HP7470A Plotter. The plotter address is 705 (code is 5 which is 0000101 on the switch).

2.0 CALIBRATION

2.1 Assure the ac and dc high voltage power supply controls are set for zero and that the supplies have been checked for discharge with the grounding stick.

2.2 Conveniently position the UUT in the high voltage test cabinet and connect the high voltage output lead and the ground lead to the UUT.

2.3 Connect the BNC connector on the Calibration Signal Coupler (CSC) through a suitable cable to the CAL OUT connector on the cabinet wall, and the CSC ground terminal to the cabinet GROUND using a conveniently short lead.

2.4 Connect the CSC bracket to the high voltage output post on the Power Separation Filter.

2.5 Close the cabinet door.

2.6 Set the breaker switch to ON on the AC Control Panel and observe POWER and XI RANGE MULTIPLIER lights are on.

2.7 Set POWER switch to ON on the Partial Discharge Detector (PDD) and adjust DISPLAY controls for a flat horizontal line of comfortable intensity and focus on the screen. Set DISPLAY SYNC to LINE.

2.8 In the CALIBRATOR section set CHARGE-pC dial and CHARGE MULTIPLIER to the desired 500 channel deflection on the PHA screen (e.g., 100 pC = 0.2pC/channel).

2.9 Set DIR CAL/IND CAL switch to DIR CAL and set ON/OFF switch to ON.

2.10 In the AMPLIFIER section set GAIN switch and VERNIER to obtain two spikes on the screen with height of the largest between 3 and 4 divisions.

2.11 On the PHA adjust POSITION and EXPAND controls to obtain between 9 and 10 divisions of horizontal deflection.

2.12 Adjust CURSOR (the bright dot in the horizontal line on the PHA screen) to CH 499 as indicated in the readout at top of the screen (full deflection is 511 channels).

2.13 Toggle CLEAR switch to DATA position and depress ACQUIRE. Observe counts on the PHA screen.

2.14 Careful inspection of the count display will reveal typically two main groupings spaced several channels apart. The VERTICAL SCALE, CLEAR DATA and ACQUIRE switches can be utilized as required to make this observation.

2.15 Carefully adjust AMPLIFIER VERNIER on the PDD such that the largest number of counts in the right hand group is positioned on the cursor at channel 499. Again, use the CLEAR DATA and ACQUIRE switches as required to enhance this adjustment.

2.16 The PDD and PHA are now calibrated such that the number of picocoulombs selected on the CHARGE-pC dial in paragraph 2.8 will be displayed in channels 0-499 on the PHA.

2.17 Set CALIBRATOR ON/OFF switch to OFF on the PDD.

2.18 Remove the calibration Signal Coupler from the Power Separation Filter.

3.0 BACKGROUND TEST

3.1 This test verifies the integrity of the high voltage lead used to connect the Power Separation Filter to the UUT. It also provides adjustment of the LLD control on the PHA to filter out any amplifier noise at low picocoulomb levels.

3.2 Disconnect the high voltage lead from the UUT and locate it a minimum of one inch from the high voltage connection of the UUT while keeping it well immersed in the FC-40.

3.3 Close the cabinet door.

3.4 Turn on the selected power supply (ac or dc) and adjust the variac for the desired voltage as read on the associated meter on the TEST SAMPLE VOLTAGE panel.

3.5 Set HORIZONTAL switch on the PHA to 1/2, toggle CLEAR switch to DATA position and depress ACQUIRE and allow the 60 second acquire time to elapse. Ideally, the background corona count will be zero. It may be necessary, however, to reposition or even replace the high voltage lead with one of better quality to achieve a zero or low count. If the counts are all in the extreme low charge area at the left side of the screen, it may be sufficient to increase the LLD setting just far enough to eliminate the low level counts.

3.6 Return the high voltage power supply controls to zero. NOTE: When turning off the dc power supply allow the indicator on the voltmeter on the DC Control panel to decay down to near zero volts before setting the INPUT VOLTAGE switch to OFF or opening the cabinet door.

3.7 Use the grounding stick to assure discharge of the high voltage at the Power Separation Filter and reconnect the high voltage lead to the UUT assuring that all high voltage points are well immersed in the fluid.

4.0 CORONA TEST

4.1 Corona Inception and Extinction Voltages

4.1.1 The Region of Interest function of the PHA will be utilized in this test. The CURSOR and REGION switch are adjusted such that the integrated number of counts in the region of channel 2 through 499 is displayed at the top of the screen.

4.1.2 Toggle CLEAR switch to DATA position and toggle REGION switch to ERASE.

4.1.3 Set CURSOR to channel 2 as indicated at upper left of screen. Toggle REGION switch to ENTER.

4.1.4 Set CURSOR to channel 499 and again toggle REGION switch to ENTER. Observe that the horizontal line between channel 2 and 499 is now highlighted on the screen.

4.1.5 Assure that the ac high voltage power supply connection has been made in the high voltage power supply cabinet.

4.1.6 Turn on the ac power supply and slowly adjust the variac to increase the output voltage while watching the integrated count number at the upper right of the PHA screen. When the counts start to accumulate, cease rotation of the variac. The corona inception voltage is as indicated on the ac meter on the Test Sample Voltage panel. NOTE: Do not exceed 12kV. The power supply will shut down when adjusted to approximately 12.3kV. If this inadvertently happens, return the variac to zero and restart the power supply as necessary.

4.1.7 After the inception voltage has been determined, slowly rotate the variac to reduce the output voltage while watching the integrated count number on the PHA screen. When the counts stop accumulating, cease rotation of the variac. The corona extinction voltage is as indicated on the ac meter on the Test Sample Voltage panel.

4.1.8 Return the variac to zero and turn the ac power supply off.

4.1.9 It may be desirable to make the inception and extinction voltage measurements several times and average the readings. If this is the case, repeat paragraphs 4.1.6 through 4.1.8 with a period of five minutes between each set of measurements.

4.2 Corona Profile

4.2.1 Two different corona profiles can be stored in the PHA simultaneously. If this versatility is going to be utilized, set the HORIZONTAL switch to 2/2 and repeat paragraph 4.1.1 through 4.1.4. Both halves of the horizontal section are now preset for display and storage. Return the HORIZONTAL switch to 1/2.

4.2.2 Turn on the selected power supply (ac or dc) and adjust the variac for the desired voltage as read on the associated meter on the TEST SAMPLE VOLTAGE panel.

4.2.3 Depress the ACQUIRE switch and observe counts accumulating on the screen. If there is no corona generated in the UUT there will be no counts indicated on the PHA screen.

4.2.4 Allow the PHA to acquire data for the preset 60 seconds (or any other specified acquire time). If a dwell time interval between application of voltage and acquisition of data has been specified, at the end of this interval set CLEAR switch to DATA position and depress ACQUIRE again.

4.2.5 If the PHA screen overflows with counts the VERTICAL SCALE switch can be adjusted as required to obtain the desired display.

4.2.6 The CURSOR can be moved across the screen to display the number of counts in any channel.

4.2.7 The CURSOR and REGION switch can be utilized as described in paragraph 4.1.1 through 4.1.4 to determine the integrated number of counts in any specified region of the display.

4.2.9 Another data profile can be stored in the PHA by switching the HORIZONTAL switch to 2/2 and repeating paragraph 4.2.3 and 4.2.4.

4.2.10 CAUTION! Data that has been acquired in a horizontal section (1/2 or 2/2) will be erased from the PHA memory and screen any time that section is selected and the CLEAR switch is toggled to the DATA position.

4.2.11 After the required data has been acquired and stored in the PHA return the power supply variac to zero and turn the power supply off.

5.0 TRANSFER DATA

5.1 Assure the Computer, Disk Drive, Monitor and Plotter are turned on.

5.2 The Computer automatically boots up to the PSE PROGRAM MANAGER * when turned on.

5.3 Select CORONA ANALYSIS from the menu on the monitor and depress the associated function key on the keyboard. Observe boot up to CORONA ANALYSIS SYSTEM and menu on the Monitor.

5.4 Select TRANSFER PHA DATA. Observe boot to PHA/HP-300 DATA TRANSFER PROGRAM and menu on the Monitor.

5.5 Select pC CONV FACTOR then enter the number of picocoulombs per channel that was chosen in calibration paragraph 2.8 (e.g., press .2 and RETURN for 0.2pC/channel).

5.6 Select RECEIVE PHA DATA and then depress I/O switch on the PHA. Observe the I/O switch lit and RECEIVING DATA with flashing highlight on the monitor.

5.7 After data transfer is completed as indicated on the monitor, select STORE PHA DATA from the menu.

5.8 Type in and enter a file name up to the asterisk on the Monitor (eight characters typically alphanumeric) to identify the file in the disk directory.

5.9 Type in and enter a file name up to the asterisk on the Monitor to become the graph title on any plots that are made in following paragraphs.

5.10 Select CAT DISK and observe that the file name entered in paragraph 5.8 is now listed in the Floppy Disk Directory.

5.11 Select EXIT PROG and observe return to CORONA ANALYSIS SYSTEM and menu on the Monitor.

5.12 Select QUIT PROG and observe return to PSE PROGRAM MANAGER and menu on the Monitor.

6.0 ANALYZE DATA

6.1 A corona data analysis program is available in this setup. The data in any file in the Floppy Disk Directory can be analyzed.

6.2 Select CORONA ANALYSIS from the PSE PROGRAM MANAGER menu. Observe boot up to CORONA ANALYSIS SYSTEM and menu on the Monitor.

* Software available from Northrop Corporation, 600 Hicks Road, Rolling Meadows IL 60008, Attn: Power Systems Engineering

6.3 Select ANALYZE DATA and observe boot to CORONA DATA ANALYSIS PROGRAM and menu on the Monitor.

6.4 Some of the menus in this program provide access to the Plotter. Before selecting HARD PLOT from any menu assure a sheet of paper has been properly loaded in the Plotter. With the PAPER lever in the LOAD position, insert the paper against the left rail and rear stop with upper corners of the paper underneath the rollers. Set PAPER lever to the HOLD position. Remove all obstacles from the paper travel area.

6.5 Select CAT DISK and observe the directory of corona data files (can be scrolled with keyboard arrows).

6.6 Obtain the file name of the file containing the data to be analyzed.

6.7 Select READ FILE and type in and enter the file name obtained in paragraph 6.6. A plot of counts versus channel and a menu will appear on the monitor.

6.8 The displayed menu and several others are available for detailed viewing and analysis of the file data. Brief explanations of some of the menu functions are included in paragraph 6.18. The following paragraphs will produce the most often viewed plot of the file data.

6.9 Select EXIT PLOTTING and observe additional menu functions.

6.10 Select POST PROCESS and observe additional menu functions.

6.11 Select CORONA CURRENT and enter a range of picocoulombs for the calculation to match the 500 channel deflection value chosen in paragraph 2.8 (e.g., 0, 100 for the 100pC in 500 channels case). Observe that the graph x axis is now 0 to 100 picocoulombs and that the total corona current and total counts are displayed above the graph.

6.12 Select FORMAT GRAPH and observe additional menu functions.

6.13 Select SET Y_{MIN} & Y_{MAX} and enter new values. Choose MIN & MAX values that result in convenient values at the coordinate lines and also that place zero somewhat above the bottom of the graph and on a coordinate line.

6.14 Select PLOT DATA and observe that the y axis now has limits as set in paragraph 6.13.

6.15 The graph is now ready to send to the Plotter. Assure a sheet of paper is in the Plotter and select HARD PLOT.

6.16 After the Plotter is finished select EXIT FORMAT, select EXIT PLOTTING, select MAIN MENU, select EXIT PROG and observe return to CORONA ANALYSIS SYSTEM and menu on the Monitor.

6.17 Select QUIT PROG and observe return to PSE PROGRAM MANAGER and menu on the Monitor.

6.18 The menu functions that are available for detailed viewing and analysis of the data are as described in the following paragraphs:

6.18.1 Selecting READ FILE provides the following:

a. ZOOM - allows expansion of an area of the graph as set by the cursor.
b. UNZOOM - restores original graph limits.
c. FORMAT GRAPH - permits changing axis limits and graph title; can be used after ZOOM.
d. HARD PLOT - sends graph to the Plotter.
e. EXIT PLOTTING - provides additional menu as listed in 6.18.2.

6.18.2 Selecting EXIT PLOTTING provides the following:

a. READ FILE - reads PHA data file as in paragraph 6.7.
b. VIEW GRAPH - plots PHA data again.
c. LIST DATA - lists PHA data in nine columns of channel counts for channels 1 through 511.
d. CAT DISK - lists directory of corona data files.
e. EXIT PROGRAM - returns to CORONA ANALYSIS SYSTEM and menu.
f. POST PROCESS - provides additional menu as listed in 6.18.3.

6.18.3 Selecting POST PROCESS provides the following:

a. COMPARE FILES - allows user to load a second file and compare it with the first.
b. REGION CALC - separates data into ten regions and recalculates y axes, region count and region current.
c. pC CONV - converts x axis from channel to picocoulomb level.
d. CORONA CURRENT - calculates corona current based on picocoulomb range entered and counts within that range.
e. MAIN MENU - returns to the menu as shown above for EXIT PLOTTING.

7.0 <u>PURGE FILE</u>

7.1 On occasion it may be desirable to remove a file from the corona data file directory. The following steps must be followed to do this:

7.2 Select UTILITY PROGRAMS from the PSE PROGRAM MANAGER menu and observe additional menu functions.

7.3 If SELECT FLOPPY is listed in the menu, select it and then select PURGE FILES. If SELECT FLOPPY is not listed, just select PURGE FILES. Observe directory of floppy disk files with arrows at the last listing.

7.4 Use the keyboard arrows to move the arrows on the screen to the file name that is to be removed.

7.5 Select SELECT FILE and observe that the file indicated by the arrows is now highlighted on the screen.

7.6 Move the screen arrows to each file to be deleted depressing SELECT FILE at each and observe highlighting of each. If a file is inadvertently highlighted move the screen arrows to this file and select UNSELECT FILE. Observe that the highlighting for this file is now deleted.

7.7 After all files to be deleted are highlighted select FINISH SELECT and observe additional menu functions.

7.8 Select CAT DISK and when the new directory listing appears, observe that the files that were highlighted are now deleted.

7.9 Select EXIT UTILITY and observe return to PSE PROGRAM MANAGER and menu on the Monitor.

CAPACITOR CORONA TEST PROCEDURE

This procedure provides the steps necessary to test the capacitors investigated in the ManTech program when using the Biddle Corona Test Set and its associated peripheral equipment in accordance with the NESD Corona Measurement Procedure. Specification MIL-C-49467 is used as a guideline for the test.

1. Turn bench on.

2. Turn computer peripherals and computer on - computer on last.

3. Plug in power cord for Pulse Height Analyzer, Cassette Recorder, etc.

4. Turn on Pulse Height Analyzer (PHA).

5. Turn on main breaker switch on AC Control Panel of Corona Test Set.

6. Connect Calibration Signal Coupler to high voltage terminal in cabinet.

7. Turn Power Switch and Calibrator Switch on on the Corona Detector Panel and assure the calibrator is set for 100pC.

8. Connect capacitor to be tested to HV lead and ground.

   a. 2.2 ufd can be tested in air.

   b. all others to be immersed in FC-40.

9. Clear the screen on the PHA and set the cursor to channel 499.

10. Depress Acquire Switch and adjust Gain Vernier on Corona Detector panel to position calibration signal counts at the cursor (channel 499) on PHA.

11. After calibration is complete, turn Calibrator off and disconnect Calibration Signal Coupler from the HV terminal.

12. Close cabinet door.

13. Comments before applying high voltage:

    a. 2.2 uf, 500Vdc gets tested up to 250Vrms max. The overcurrent trip circuit is set to trip at 200mA which will occur at approximately 250Vrms. Don't leave the 250V applied to the capacitor longer than necessary to make the measurement.

    b. .022 uf and .024 uf, 1kVdc get tested up to 700Vrms max. Be careful not to overvoltage this one.

    c. .01 uf, 4kVdc gets tested up to 2800 Vrms max.

d. Adjust meter scale selector switches on Corona Test Set as desired for ease of reading the meters.

e. Set PHA cursor at channel 249 (50pC) for ease of determining CIV at the 50pC level.

f. Counts at 50pC should be repetitive for determining CIV.

g. Try to make measurement without too much delay to prevent subjecting the capacitor to more corona than necessary.

14. Turn on high voltage and slowly adjust variac upwards while watching PHA screen and the HV meter. Watch the PHA screen for repetitive counts in the area of the cursor (channel 249). If this condition occurs, stop adjusting the variac and note the voltage on the meter - this is CIV. If no counts occur around channel 249 be careful not to exceed the maximum test voltage specified in step 13.

15. After CIV has been determined, slowly reduce the variac until the occurrence of counts at channel 249 ceases - this is CEV.

16. For the 2.2 uf capacitor, increase high voltage until the overcurrent circuit trips out. The voltage at trip is retained on the meter on the variac panel until overcurrent reset is depressed.

17. After CIV and CEV determination, reduce high voltage to zero.

18. Enter the CIV and CEV data into the computer.

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1.2 Capacitors

CERAMIC

Ceramic high voltage capacitors have, historically, been troublesome components for power supply manufacturers. Specifications and acceptance criteria are poorly defined at best. There are several military specifications in existance, with MIL-C-123 being heavily used, but their true utility is in question. As part of this program a significant effort was undertaken to examine the quality under stress of existing ceramic high voltage capacitors purchased "off-the-shelf' primarily to supplier specifications. Table 1 lists the parts used in this exercise. Note that there were two capacitor/voltage ratings purchased from five different suppliers.

QUANT	SUPPLIER	CAP-UF	V RATING	DIELECTRIC	DIEL. TYPE	LAYERS	COATED
100	Supplier B	0.022	1,000	CERAMIC	X7R	1	N
100	Supplier C	0.022	1,000	CERAMIC	X7R	1	Y
100	Supplier A	0.024	1,000	CERAMIC	X7R	1	N
100	Supplier D	2.200	500	CERAMIC	X7R	2	N
100	Supplier E	2.200	500	CERAMIC	X7R	2	N
100	Supplier C	2.200	500	CERAMIC	X7R	10	N

Table 1 CAPACITOR TEST ITEMS

The purchased parts underwent the testing program shown in Figure 1.

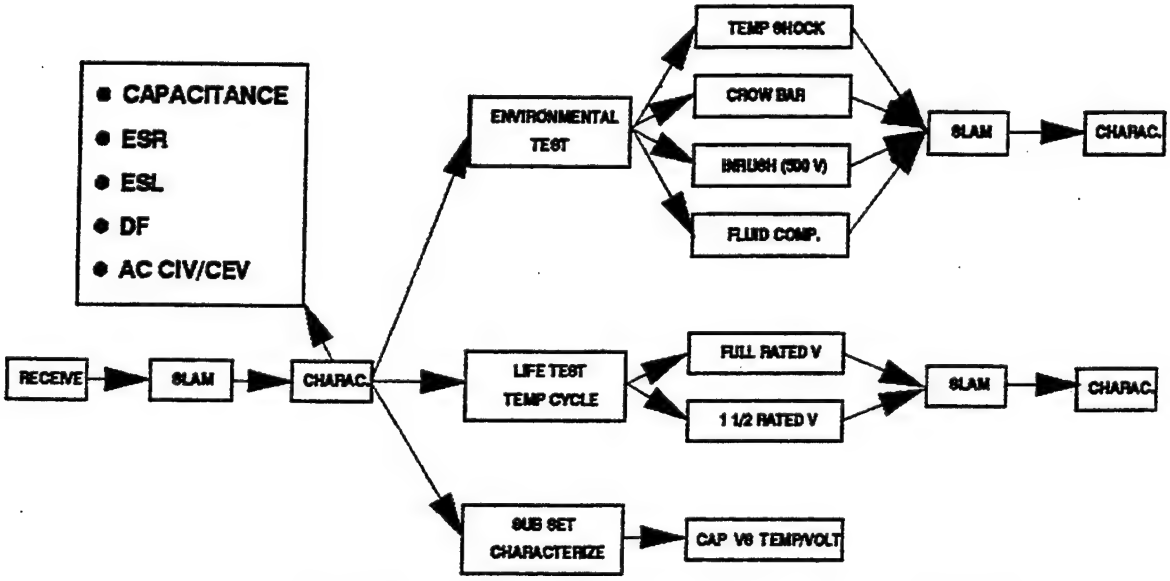

Figure 1 CERAMIC CAPACITOR TEST PROGRAM

Environmental test details are as described in Table 2.

TEST DESCRIPTION	TEST MEDIA	TEST RESULTS	COMMENTS
TEMPERATURE SHOCK	AIR	50 CYCLES IN SHUTTLE	-55 TO +95 C
CROW BAR	AIR	100 PULSES, RATED V	80 AMP PEAK
INRUSH CURRENT	AIR	100 PULSES, RATED V	65 AMPS PEAK
FLUID COMPATABILITY	FC 77	500 HOURS, STATIC	+100 C
RATED V LIFE TEST	MINERAL OIL	500 HRS, V APPLIED	-55 TO +100 C
1-1/2 V LIFE TEST	MINERAL OIL	1795 HRS, V APPLIED	-55 TO +100 C
CAP. VS TMP/VOLT	AIR	PLOTS	TO RATED V

Table 2 ENVIRONMENTAL TEST RESULTS

The final report for this program describes the results of this capacitor program in significant detail. However, the procedures and test equipment used to conduct the tests shown in Table 3 are included in these Manufacturing Guidelines as listed below.

Para. No.	Description
1.1	Corona Test
1.2.1	Impedance Test
1.2.2	Leakage Current Test
1.2.3	Crow Bar Test
1.2.4	InRush Current Test
1.2.5	V & T Coefficients
1.2.6	Acoustical Tests

Table 3 DETAILED TEST PROCEDURE LISTINGS

Included in the above listings are computer code when required, schematic diagrams, parts lists and detailed test instructions. The Corona test section includes the use of a Pulse Height Analyzer (PHA). The Accoustical evaluations section includes descriptions for conduction Scanning Laser Acoustical Microscope (SLAM) tests and C-Mode Scanning Acoustical Microscope (C-SAM) tests.

MICA

Three mica paper capacitor types from five manufacturers were characterized as follows:

1. Determination of conformance to requirements

2. Assessment testing intended to establish relative rankings of the various manufacturers products under selected operating conditions

The evaluations performed on the capacitors are described below:

THERMAL SHOCK TESTS

Thermal shock testing of the mica paper capacitors is performed to determine the effects of thermal stresses on the physical - mechanical integrity of the devices. The physical - mechanical integrity is a major determinant in the HV behavior of the capacitor.

To assess the effects of thermal stressing, ac and dc corona measurements are made before and after the thermal stress exposure. Physical - mechanical changes in the device will alter the corona characteristics.

Six capacitors of each type from each manufacturer were subjected to thermal shock cycling. The conditions employed are given in Table 4. Before and after the cycling each device was ac and dc corona characterized and subjected to dc DWV tests. The test voltages used in these characterizations are shown in Table 5. All high voltage testing was done in Freon TF at room temperature. These conditions eliminate discharge phenomena due to leads and external surface effects at low pressures (at or near 1. atmosphere).

PARAMETER	VALUE
Temp. Range	-55° to 125° C
Transfer Time	< 15 seconds
Dwell at Temp. extremes	1.0 hours
No. of Cycles	25

Table 4 THERMAL SHOCK CONDITIONS FOR HV MICA PAPER CAPACITORS

Test Type	Capacitor Rating	Maximum Test Voltage
dc corona	3 kv	CIV or 4.5 KVDC
	5 kv	CIV or 7.5 KVDC
	10 kv	CIV or 13.5 KVDC
dc DWV	3 kv	4.5 kv
	5 kv	7.5 kv
	10 kv	13.5 kv
ac corona	3 kv	CIV or 3.0 KVAC
	5 kv	CIV or 5.0 KVAC
	10 kv	CIV or 10.0 KVAC

Table 5 MAXIMUM TEST VOLTAGES EMPLOYED IN THE HV TESTING OF MICA PAPER CAPACITORS

A brief summary of the results include the following observations:

- ac corona levels including both CIV and CEV values changed less than 20 percent for all devices from all manufacturers
- dc corona levels were essentially unchanged for all devices from all manufacturers; no levels exceeded 20 picocoloumbs per second before or after thermal shock
- no DWV failures occurred either before or after thermal shock for any device from any manufacturer

ACCELERATED LIFE TESTS

Accelerated life testing of the three capacitor types from the five manufacturers was performed to

- establish relative operating life rankings of each device type for the five manufacturers
- identify correlations between device life times and their corona characteristics

The life test conditions employed in these evaluations are outlined in Table 6. In these tests a total of 12 devices of each capacitor type from each manufacturer were evaluated. All devices under test

have passed a 100 hour burn-in. Six of the 12 devices from each type have been subjected to thermal shock cycling prior to the tests. Also prior to the start of the tests each device was subjected to ac and dc corona characterization and to dc DWV testing.

Device type	Sequence
3kv - 22nF	4.5kv → 4.5kv → 4.5kv
5kv - 15nF	7.5kv → 7.5kv → 7.5kv
10kv - 10nF	13.5kv → 13.5kv → 13.5kv
Temperature (°C)	25 → 85 → 125
Dwell time (hrs)	24 → 100 → 2000

Table 6 CONDITIONS USED IN THE ACCELERATED LIFE TESTING OF THE HV MICA PAPER CAPACITORS

At approximately 1100 hours the life tests were interrupted to:

- o confirm the observed failures occurring during this period
- o determine both ac and dc corona characteristics after this period of accelerated testing

The failures were confirmed by subjecting the units to a 20 second DWV test at the appropriate life test voltage. Devices failing these tests were considered life test failures. Based on these results a summary of the life test failures occurring during the initial 1100 hours of testing are given in Table 7.

Deivice Type	MFGR	No. of Failures	
3 kv - 22 nF	A	0	(11)
	B	1	(12)
	C	3	(10)
	D	0	(12)
	E	1	(11)
5 kv - 15 nF	A	0	(12)
	B	0	(12)
10 kv - 10 nF	A	0	(04)
	B	0	(12)
	C	9	(09)
	D	1	(12)
	E	0	(12)

( ) - denotes number devices starting test

Table 7 CONFIRMED FAILURES OCCURRING DURING THE INITIAL 1100 HOURS OF ACCELERATED LIFE TESTING OF THE HV MICA PAPER CAPACITORS

DC corona characterization is recommended as a further evaluation technique. Suggested measurement conditions are:

- A 30 second charge accumulation period at the rated voltage of the device - all devices to be measured
- A five minute charge accumulation period at the life test voltage - all devices to be measured
- A 20 minute charge accumulation period at the life test voltage - the high and low charge producing devices for each manufacturer and type are to be measured

The objective in these dc corona measurements are:

- To observe if the ranking of the capacitor corona response changes when the measurement time and voltage is changed
- to determine which measurement condition more adequately reflects the device quality as determined by the failure occurrences during the remainder of the life tests

The need to consider these variations in measurement conditions is based on the nature of the dc corona process, namely that dc corona discharges are of a random, recurrent nature.

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Impedance Measurement
Test Procedure

1. Connect the HP 4192A Impedance Analyzer to a PC with the GPIB interface card installed. The DIP switch on the 4192 should be set to "0010001". Use a 16047A test adapter or the PSE adapter to connect the capacitor being tested to the analyzer. The 4192 requires a one hour warm up for the most accurate measurements.

2. Start the computer program by typing "IMPED" and pressing the <ENTER> key.

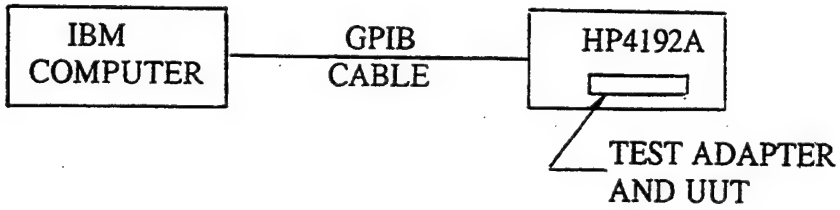
3. The first option is to delete the previous data file. Press "Y" to erase any old data. Any other key appends new data to the end of any old data.

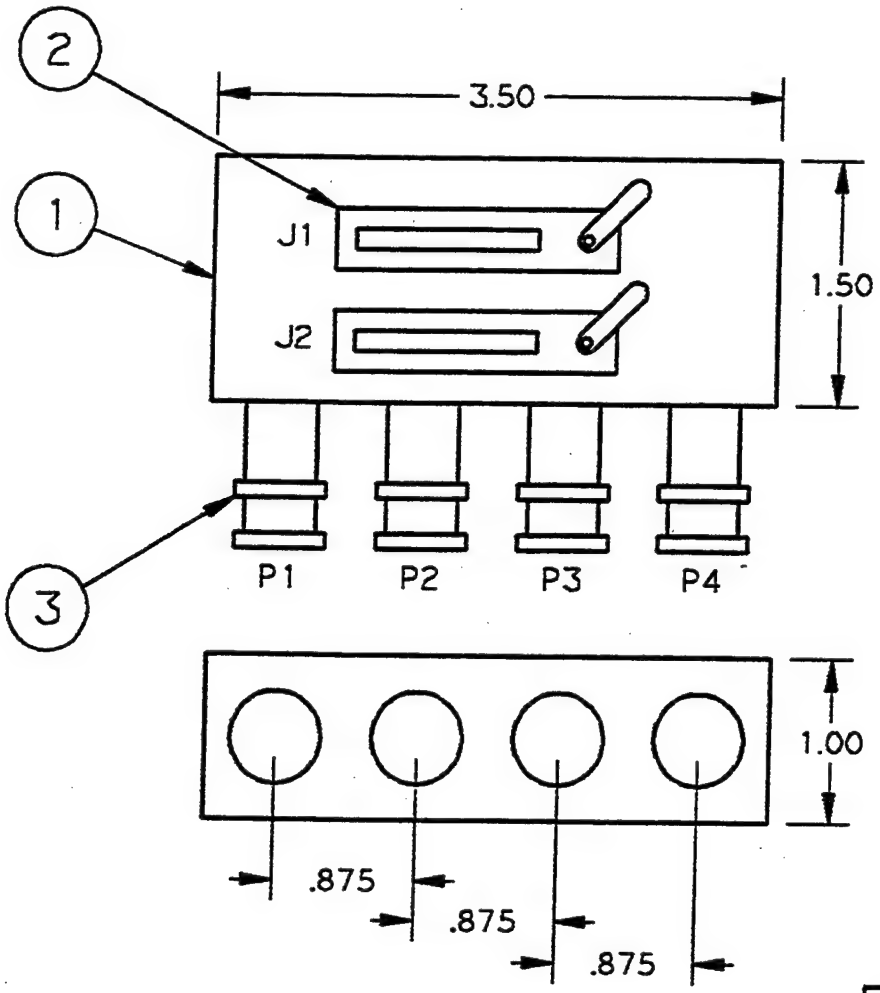
4. The next option is to change the test frequencies. If any changes are made, the new test frequencies are saved and used as the default.

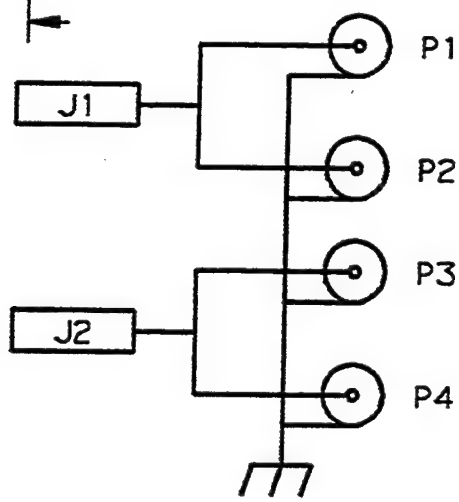
5. The last step is to enter the first serial number to be tested. The serial number is incremented automatically as the test continues and is saved with the data.

6. Press <ENTER> to start the test. The data is displayed on the computer and saved to the hard disk at the same time. The next serial number to be tested is also displayed. If the displayed serial number is wrong, enter the correct number. Use the backspace key to edit the number, if required.

7. Type "EXIT" as the serial number to stop the program and save the data file to a floppy disk. The data is stored in the file "CAP.DTA".







ADAPTER SCHEMATIC

PARTS LIST

FIND NO.	DESCRIPTION	QTY.
1.	BOX ALUMINUM	1
2.	SOCKET, ZERO INSERTION FORCE. TEXTOOL P/N 210-2599	2
3.	CONNECTOR, BNC PLUG. AMPHENOL P/N 15875	4

CAPACITOR TEST ADAPTER FOR HP4192A IMPEDANCE ANALYZER.

```
' HP4192A Impedance Analyzer  "IMPED.BAS"
' Set HPIB switch #6 to "comma" for this program
' Refer to manual page 3-73, note #1
' Written in QuickBasic 4.5 by Neils Kruse
' 1/15/92

REM $INCLUDE: 'C:\GPIB-PC\QBDECL.BAS'    ' Use this line for the 8 bit card
'REM $INCLUDE: 'C:\AT-GPIB\QBDECL.BAS'   ' Use this line for the 16 bit card

DECLARE SUB gpiberr (msg$)
DECLARE SUB WriteData ()
DECLARE SUB ReadData ()
DECLARE SUB BufInput (StringVar$, Limit%)
DECLARE FUNCTION GetFreq! (freq%)
DECLARE FUNCTION StrVal! (Txt$)

DIM SHARED rd AS STRING * 30
DIM SHARED BD AS INTEGER
DIM SHARED nf AS INTEGER
DIM SHARED Serno AS INTEGER
DIM SHARED F(1 TO 7) AS INTEGER
DIM SHARED D(1 TO 7) AS STRING
DIM SHARED Z(1 TO 7) AS SINGLE
DIM SHARED P(1 TO 7) AS SINGLE
 F(1) = 1
 F(2) = 10
 F(3) = 30
 F(4) = 100
 F(5) = 300
 F(6) = 1000
 F(7) = 10000
 nf% = 7

' Read defaults from disk file

OPEN "IMPED.DEF " FOR APPEND AS #1  ' CREATE FILE IF IT DOES NOT EXIST
CLOSE #1
OPEN "IMPED.DEF" FOR INPUT AS #1
IF NOT EOF(1) THEN                  ' READ DATA
    INPUT #1, F(1), F(2), F(3), F(4), F(5), F(6), F(7)
    CLOSE #1
ELSE
    CLOSE #1
    OPEN "IMPED.DEF" FOR OUTPUT AS #1  ' WRITE DATA IF IT DOES NOT EXIST
    WRITE #1, F(1), F(2), F(3), F(4), F(5), F(6), F(7)
    CLOSE #1
END IF

CLS

rd$ = SPACE$(30)
INPUT ; "Erase capacitor data? (Y/N)"; rd$
rd$ = UCASE$(rd$)

IF LEFT$(rd$, 1) = "Y" THEN                 ' Erase "CAP.DTA", DEFAULT IS NO
    OPEN "CAP.DTA" FOR OUTPUT AS #1
    CLOSE #1
END IF
CLS
```

```
rd$ = SPACE$(30)
INPUT ; "Change default test frequency? (Y/N)"; rd$
rd$ = UCASE$(rd$)

IF LEFT$(rd$, 1) = "Y" THEN                    ' Erase IMPED.DEF, DEFAULT IS NO
    LOCATE 3, 2
    x = GetFreq(1)
    LOCATE 6, 2
    x = GetFreq(2)
    LOCATE 9, 2
    x = GetFreq(3)
    LOCATE 12, 2
    x = GetFreq(4)
    LOCATE 15, 2
    x = GetFreq(5)
    LOCATE 18, 2
    x = GetFreq(6)
    LOCATE 21, 2
    x = GetFreq(7)

    OPEN "IMPED.DEF" FOR OUTPUT AS #1
    WRITE #1, F(1), F(2), F(3), F(4), F(5), F(6), F(7)
    CLOSE #1
END IF

CLS

CALL SendIFC(0)                          ' Clear interface
IF IBSTA% < 0 THEN
    CALL gpiberr("SendIFC error")
    STOP
END IF

CLS
CALL IBFIND("DEVA", BD%)      'Assign the unit descripter to bd%
IF (BD% < 0) THEN
    CALL gpiberr("Ibfind error")
    STOP
END IF

CALL IBCLR(BD%)                 'Clear the HP4192A

WRT$ = "A1B1T3F1"
CALL IBWRT(BD%, WRT$)


LOCATE 3, 2
PRINT " What is the first serial number? ";
char$ = SPACE$(4)
StringVar$ = SPACE$(4)
WHILE char$ <> CHR$(13)
    char$ = INKEY$
    IF char$ <> "" THEN
        StringVar$ = StringVar$ + char$
        PRINT char$;
    END IF
WEND

Serno% = VAL(StringVar$)
```

```
CLS
LOCATE 3, 2
PRINT " Press <ENTER> to start the test"
DO
LOOP WHILE INKEY$ = ""

DO WHILE INKEY$ <> CHR$(0) + "v"
    CLS
    CALL ReadData
    LOCATE 3, 2
    PRINT "Data for serial number " + STR$(Serno%)
    PRINT

    FOR i = 1 TO nf%
        Z(i) = StrVal!(MID$(D(i), 5, 11))
        P(i) = StrVal!(MID$(D(i), 21, 11))
        PRINT F(i), D(i); "    " + STR$(Z(i)), STR$(P(i))
    NEXT i

    CALL WriteData

    Serno% = Serno% + 1

    LOCATE 15, 2
    PRINT " Press <ENTER> to test serial number " + STR$(Serno%)
    PRINT "Or enter a different serial no. ";
    COLOR 0, 7
    PRINT SPACE$(4)

    LOCATE 17, 1
    COLOR 7, 0
    PRINT "Or type " + "EXIT" + " to quit"

    COLOR 0, 7
    LOCATE 16, 33
    a$ = SPACE$(4)
    CALL BufInput(a$, 4)
    COLOR 7, 0

    IF VAL(a$) <> 0 THEN
        Serno% = VAL(a$)
    END IF

    IF UCASE$(a$) = "EXIT" THEN
        LOCATE 19, 3
        rd$ = SPACE$(30)
        INPUT ; "Exit program? (Y/N)"; rd$
        rd$ = UCASE$(rd$)

        IF LEFT$(rd$, 1) = "Y" THEN
            EXIT DO
        END IF

    END IF

LOOP
        CLS
        rd$ = SPACE$(30)
        INPUT ; "Save data to floppy disk? (Y/N)"; rd$
        rd$ = UCASE$(rd$)
```

```
        IF LEFT$(rd$, 1) = "Y" THEN
            CLS
            r$ = SPACE$(1)
            PRINT "Insert a floppy and press the letter"
            INPUT ; "of the drive to be used"; r$
            r$ = MID$(UCASE$(r$), 1, 1)
            cmd$ = "COPY C:\CAP.DTA " + r$ + ":"
            LOCATE 4, 1
            PRINT cmd$
            SHELL (cmd$)

        END IF

END
```

```
SUB BufInput (StringVar$, Limit%)
Length% = 0
StringVar$ = ""

'Loop waiting for input. Enter terminates the routine
WHILE char$ <> CHR$(13)
char$ = INKEY$
    IF char$ <> "" THEN
        IF (Length% < Limit%) OR (char$ = CHR$(8)) THEN
            SELECT CASE char$
            CASE " " TO "~"     ' Other printable character
                StringVar$ = StringVar$ + char$
                PRINT char$;
                Length% = Length% + 1
            CASE CHR$(8)        ' Backspace was entered
                IF Length% <> 0 THEN
                Length% = Length% - 1
                StringVar$ = LEFT$(StringVar$, Length%)
                CurrX% = CSRLIN
                CurrY% = POS(0) - 1
                LOCATE CurrX%, CurrY%
                PRINT " "
                LOCATE CurrX%, CurrY%
                END IF
            END SELECT
        ELSE
            PLAY "o1A132"
        END IF
    END IF
WEND

END SUB

FUNCTION GetFreq (freq%)

    PRINT " TEST FREQUENCY " + STR$(freq%) + " IS " + STR$(F(freq%)) + " KHz"
    PRINT " INPUT NEW VALUE ";
    char$ = SPACE$(4)
    StringVar$ = SPACE$(4)
    WHILE char$ <> CHR$(13)
        char$ = INKEY$
        IF char$ <> "" THEN
            StringVar$ = StringVar$ + char$
            PRINT char$;
        END IF
    WEND

    IF VAL(StringVar$) <> 0 THEN
```

```
        F(freq%) = VAL(StringVar$)
    END IF

    CurrX% = CSRLIN - 1
    LOCATE CurrX%, 18
    PRINT STR$(F(freq%)) + " KHz    "

END FUNCTION

'==========================================================================
'                          Subroutine GPIBERR
'  This subroutine will notify you that a NI-488 function failed by printing
'  an error message.  The status variable IBSTA% will also be printed
'  in hexadecimal along with the mnemonic meaning of the bit position.
'  The status variable IBERR% will be printed in decimal along with the
'  mnemonic meaning of the decimal value.  The status variable IBCNT% will
'  be printed in decimal.
'
'  The NI-488 function IBONL is called to disable the hardware and software.
'
'  The STOP command will terminate this program.
'==========================================================================
'
SUB gpiberr (msg$) STATIC

  PRINT msg$

  PRINT "ibsta = &H"; HEX$(IBSTA%); " <";
  IF IBSTA% AND EERR THEN PRINT " ERR";
  IF IBSTA% AND TIMO THEN PRINT " TIMO";
  IF IBSTA% AND EEND THEN PRINT " END";
  IF IBSTA% AND SRQI THEN PRINT " SRQI";
  IF IBSTA% AND RQS THEN PRINT " RQS";
  IF IBSTA% AND CMPL THEN PRINT " CMPL";
  IF IBSTA% AND LOK THEN PRINT " LOK";
  IF IBSTA% AND RREM THEN PRINT " REM";
  IF IBSTA% AND CIC THEN PRINT " CIC";
  IF IBSTA% AND AATN THEN PRINT " ATN";
  IF IBSTA% AND TACS THEN PRINT " TACS";
  IF IBSTA% AND LACS THEN PRINT " LACS";
  IF IBSTA% AND DTAS THEN PRINT " DTAS";
  IF IBSTA% AND DCAS THEN PRINT " DCAS";
  PRINT " >"

  PRINT "iberr = "; IBERR%;
  IF IBERR% = EDVR THEN PRINT " EDVR <DOS Error>"
  IF IBERR% = ECIC THEN PRINT " ECIC <Not CIC>"
  IF IBERR% = ENOL THEN PRINT " ENOL <No Listener>"
  IF IBERR% = EADR THEN PRINT " EADR <Address error>"
  IF IBERR% = EARG THEN PRINT " EARG <Invalid argument>"
  IF IBERR% = ESAC THEN PRINT " ESAC <Not Sys Ctrlr>"
  IF IBERR% = EABO THEN PRINT " EABO <Op. aborted>"
  IF IBERR% = ENEB THEN PRINT " ENEB <No GPIB board>"
  IF IBERR% = EOIP THEN PRINT " EOIP <Async I/O in prg>"
  IF IBERR% = ECAP THEN PRINT " ECAP <No capability>"
  IF IBERR% = EFSO THEN PRINT " EFSO <File sys. error>"
  IF IBERR% = EBUS THEN PRINT " EBUS <Command error>"
  IF IBERR% = ESTB THEN PRINT " ESTB <Status byte lost>"
  IF IBERR% = ESRQ THEN PRINT " ESRQ <SRQ stuck on>"
  IF IBERR% = ETAB THEN PRINT " ETAB <Table Overflow>"
```

```
    PRINT "ibcnt = "; IBCNT%

 '  Call the IBONL function to disable the hardware and software.

    CALL IBONL(brd0%, 0)

    STOP

 END SUB

 SUB ReadData

 FOR i = 1 TO nf%
     OutFreq$ = STR$(F(i))
     WRT$ = "FR" + OutFreq$ + "EN"
     CALL IBWRT(BD%, WRT$)

     WRT$ = "EX"
     CALL IBWRT(BD%, WRT$)
     rd$ = SPACE$(30)
     CALL IBRD(BD%, rd$)
     F(i) = VAL(RTRIM$(OutFreq$))
     D(i) = rd$
NEXT i

END SUB

DEFINT A-Z
FUNCTION StrVal! (Txt$) STATIC

 ' Converts a string to a number. Must be a + or - in front of exponent.
 ' The range of valid numbers is -9.99999E+9 to +9.99999E+9.

 Temp$ = ""
 Power! = 1
 Epos% = 0

 'Find the position of the "e"

 IF INSTR(Txt$, "e") > 0 OR INSTR(Txt$, "E") > 0 THEN
    Epos% = INSTR(Txt$, "e") OR INSTR(Txt$, "E")
 ELSE
    StrVal! = -8.88888E+08
    EXIT FUNCTION
 END IF

 ' If first character is "+" then loose it
 ' Trim off any characters after the "e"

 IF LEFT$(Txt$, 1) = "+" THEN
    Temp$ = MID$(Txt$, 2, Epos% - 1)
 ELSE
    Temp$ = MID$(Txt$, 1, Epos% - 1)
 END IF


 ' Find the exponent value

 x% = VAL(MID$(Txt$, Epos% + 2, 2))
```

```
 ' Find the exponent sign and calculate the power

 IF MID$(Txt$, Epos% + 1, 1) = "+" THEN
    FOR J = 1 TO x%
        Power! = Power! * 10
    NEXT J
 ELSE
    FOR J = 1 TO x%
        Power! = Power! * .1
    NEXT J
 END IF

 StrVal! = Power! * (VAL(Temp$))

END FUNCTION

SUB WriteData
    OPEN "CAP.DTA" FOR APPEND AS #1
    WRITE #1, STR$(Serno%), F(1), Z(1), P(1), F(2), Z(2), P(2), F(3), Z(3), P(3)
    CLOSE #1
END SUB
```

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

	Pages
1.0 Components	
1.2 Capacitors	
1.2.2 Leakage Current Measurement Test Procedure	1.2-19 to 1.2-31

Capacitor Leakage Current Measurement
Test Procedure

1) Connect the leakage current test fixture to the PC printer port (LPT1) and the Keithley 617 Electrometer to the GPIB interface card. Set the high voltage power supply to the rated voltage of the capacitors being tested.

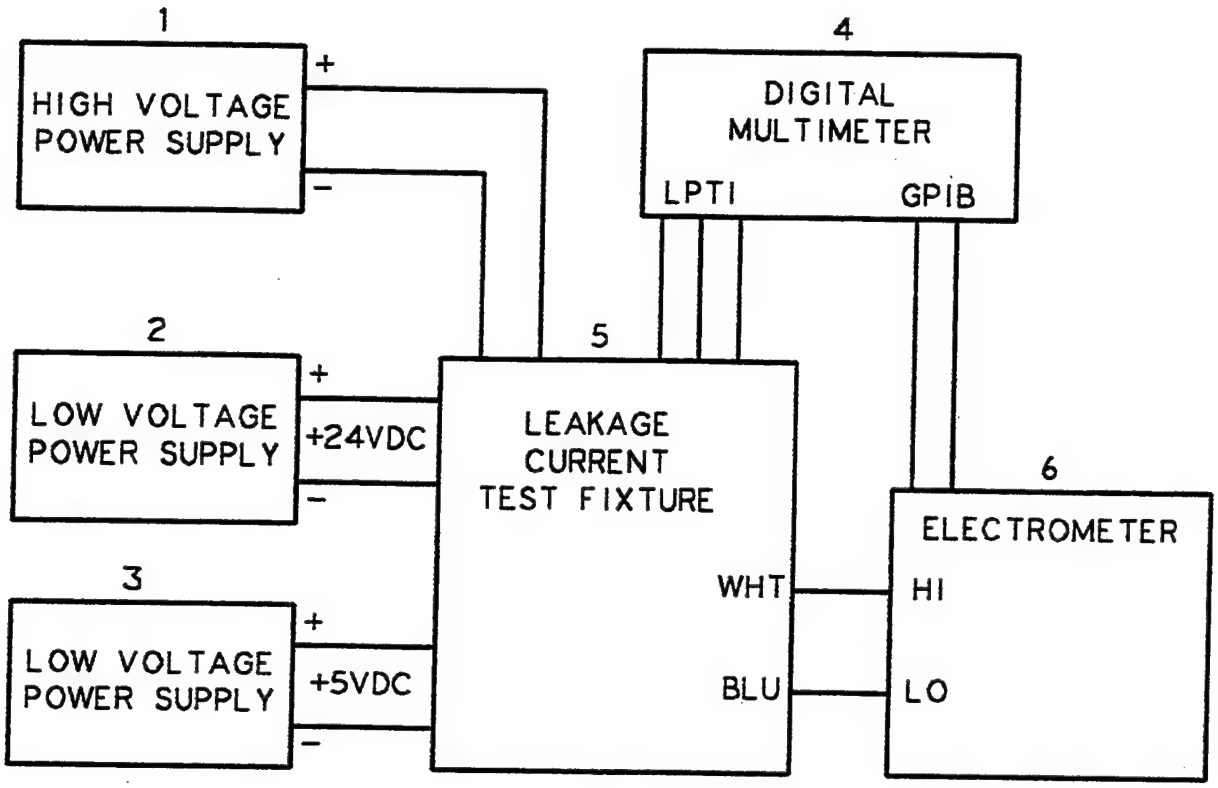
2) Start the computer program by typing "DCLEAK" and pressing the <ENTER> key.

3) The first option is to delete the previous data file. Press "Y" to erase any old data. Any other key appends new data to the end of the old data file.

4) The next step is to enter the serial number of the capacitor being tested. The serial number is incremented automatically as the test continues and is saved with the data.

5) Press <ENTER> to start the test. The data is taken and saved to the hard drive.

6) Change the capacitor to be tested and enter the correct serial number if the displayed number is incorrect. Press <ENTER> to continue the test or type "EXIT" to stop testing and save the data to a floppy disk. The data is saved to a file named "LEAK.DTA".



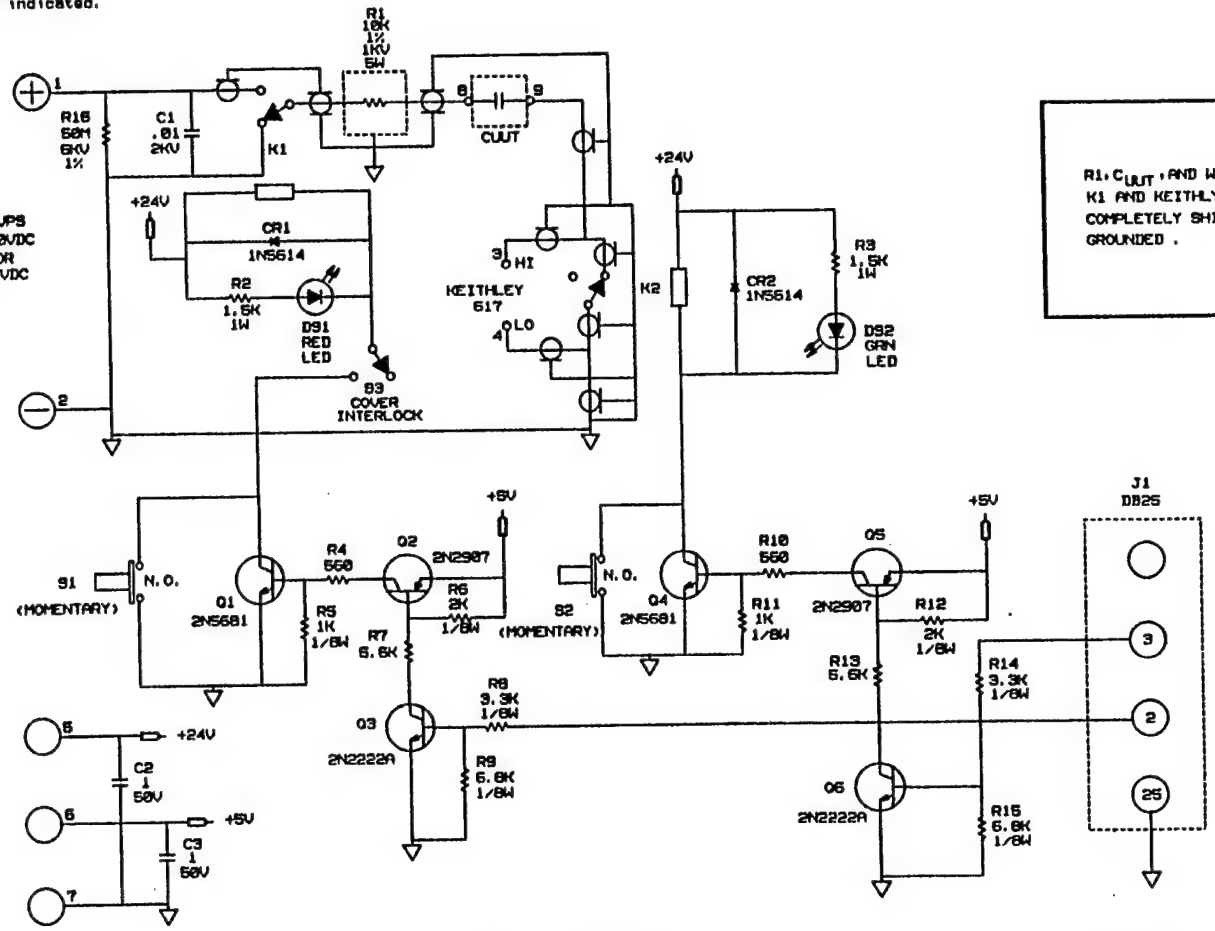
1. REGULATED HIGH VOLTAGE POWER SUPPL 0 -1 KVDC @ 1 MA.
2. REGULATED LOW VOLTAGE POWER SUPPLY. 0 - 30VDC @ 300 MA.
3. REGULATED LOW VOLTAGE POWER SUPPLY. 0 - 10VDC @ 50MA.
4. PROGRAMMED DIGITAL COMPUTER WITH STANDARD 25 PIN INTERFACE CONNECTOR TO TEST FIXTURE.
5. LEAKAGE CURRENT TEST FIXTURE. SEE ATTACHED SCHEMATIC AND PARTS LIST.
6. ELECTROMETER, KEITHLEY 617.

THE DIMENSIONING AND TOLERANCING PRACTICE USED ON THIS DRAWING IS IN ACCORDANCE WITH ANSI Y14.5M-1982

/home1/kruse/CP1/BITS.INRUSH.1.4
LAST_MODIFIED=Tue Nov 21 08:27:11 1995

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	XA		951121	

Notes:
1. All capacitances are uF unless otherwise indicated.
2. All resistances are Ohms. K is kilohms. Tolerances are 5% unless otherwise indicated.
3. Highest Ref Degn: C9;R16;Q6;CR2;S3;DS2;J1;K2.



R1, C_{UUT}, AND WIRING BETWEEN K1 AND KEITHLY WILL BE COMPLETELY SHIELDED. SHIELDING GROUNDED .

NOTICE: THIS IS A CAD DRAWING! IF MANUAL CHANGES ARE MADE, THIS DRAWING SHALL NOT BE RELEASED UNTIL THE CAD DATA-BASE HAS BEEN UPDATED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AFTER FINISHING
TOLERANCES ON
3 PLACE DECIMAL : ±.005
2 PLACE DECIMAL : ±.010
ANGLES : ±0.50 DEG
GEOMETRICAL TOLERANCES APPLY TO FINISH SIZES
PARTS SHALL BE CLEAN AND FREE OF BURRS AND SHARP EDGES
ALL SURFACES 125 √ AFTER FINISHING

ORIGINAL CONTRACT NO.
DRAWN N. KRUSE
CHK
CHK
TPS ENG
PROD ASSURANCE
PROJ ENGR
PROJ ENGR
TECH DATE

NORTHROP
Electronic Systems Division
Rolling Meadows Site
Rolling Meadows, Illinois

SCHEMATIC, CAPACITOR LEAKAGE CURRENT TEST FIXTURE

SIZE D | CAGE CODE 26916 | DWG NO.

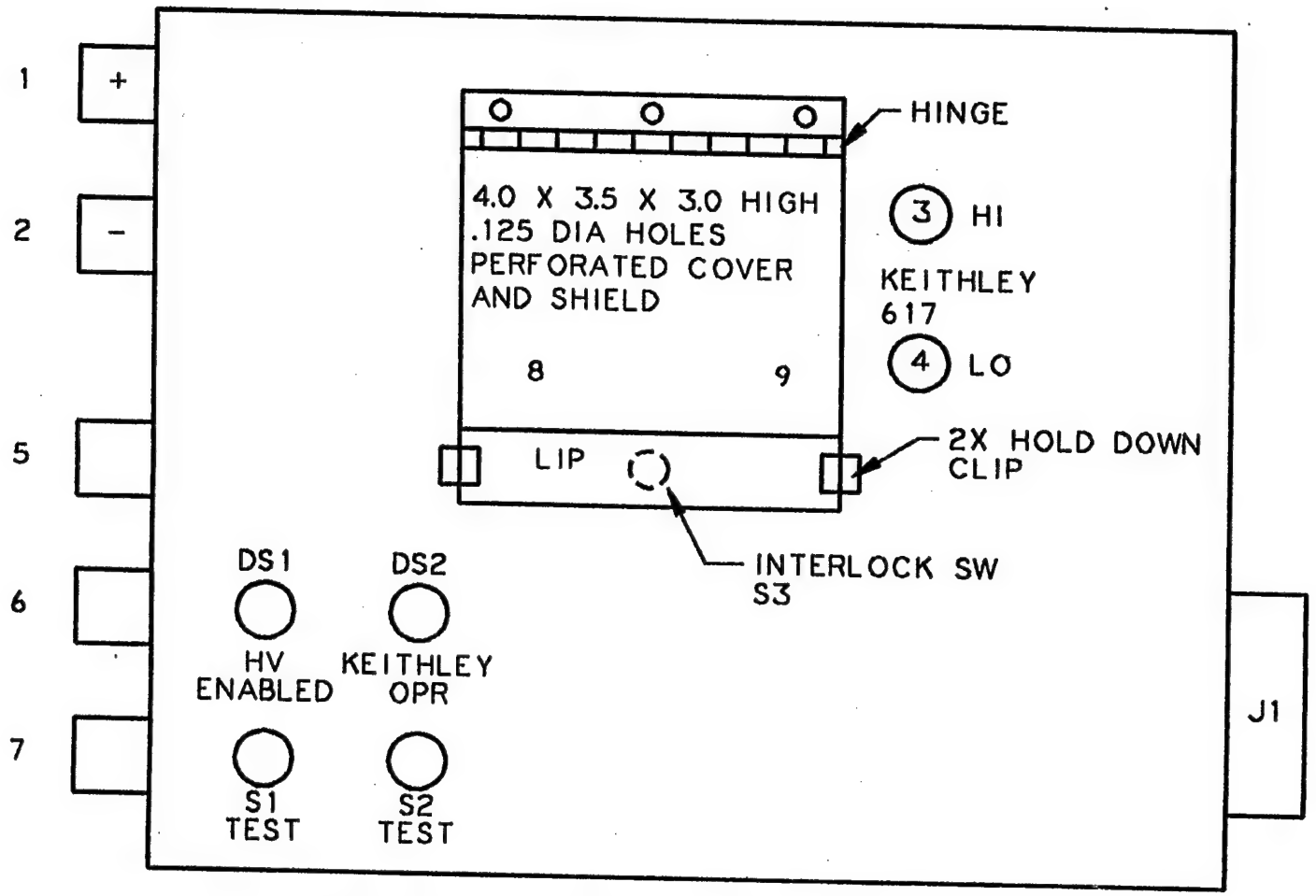
SCALE: NONE | SHEET 1 OF 1

PARENTHETICAL DATA MARKED WITH AN ASTERISK (*) IS PECULIAR TO A PRIOR MANUFACTURER. IT DOES NOT TAKE PRECEDENCE OVER ANY OTHER DATA ON THIS DRAWING AND IS NOT CONTRACTUALLY BINDING ON EITHER THE CONTRACTOR OR THE GOVERNMENT.

1.2-7.1

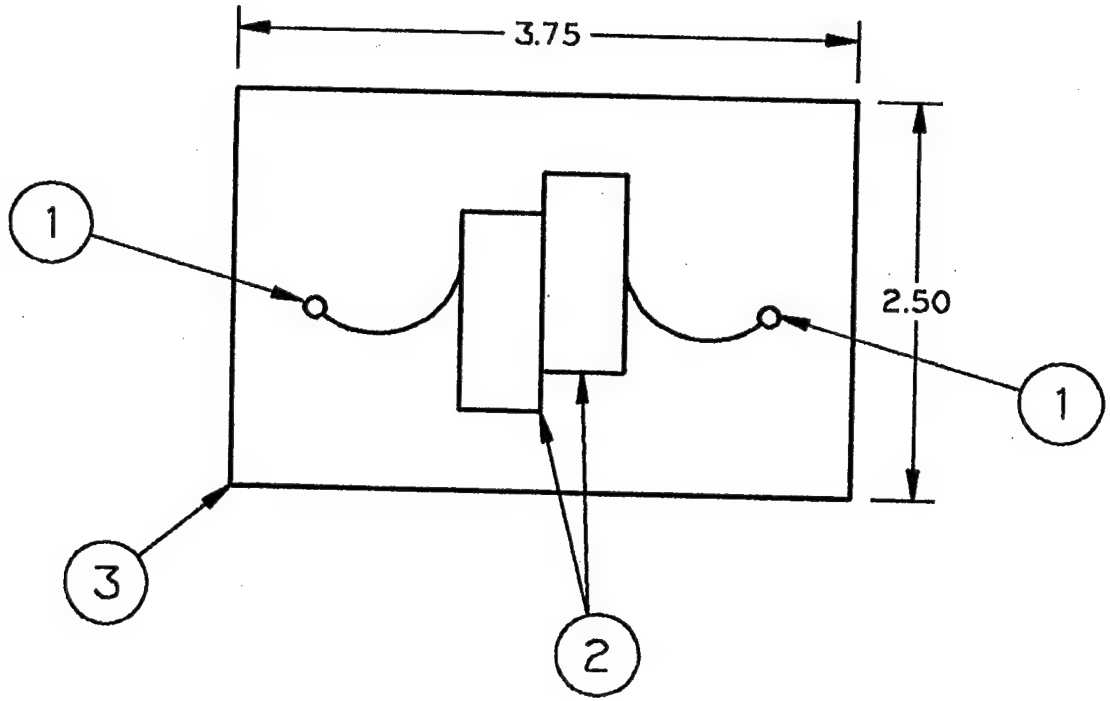
CAPACITOR LEAKAGE CURRENT TEST FIXTURE

C1	0.01uFd +/-10%, 2KV
C2,3	1.0 uFd +/-10%, 50V, CKR06
R1	10K OHM +/-1%, 1KV, 5W, MS260 CADDOCK
R2,3	1500 OHM +/-5%, 1W, RCR32
R4,10	560 OHM +/-5%, 1/4W, RCR07
R5,11	1K OHM +/-5%, 1/8W, RCR05
Q1,4	2N5681, TO-5, WITH RADIATOR, MOTOROLA
CR1,2	IN5614, 1A, 200V, UNITRODE
Q2,5	2N2907A, TO-18
Q3,6	2N2222A, TO-18
S1,2	PUSH BUTTON, 115V, 1A, NORMALLY OPEN - PUSH TO CLOSE, MOMENTARY CONTACT
DS1	LED, RED (1.2V @15MA)
DS2	LED, GREEN (2V @15MA)
J1	DB25 FEMALE CONNECTOR (25 PIN, D-TYPE CONNECTOR)
K1	HIGH VOLTAGE RELAY, 1KVDC, SPDT, 26.5VDC COIL
K2	DPDT, 24VDC COIL, 5A CONTACTS, 115VAC ISOLATION (TYPICAL - POTTER BRUMFIELD K10P11A1524)
R6,12	2K OHM +/-5%, 1/8W, RCR05
R7,13	5.6K OHM +/-5%, 1/4W, RCR07
R8,14	3.3K OHM +/-5%, 1/8W, RCR05
R9,15	6.8K OHM +/-5%, 1/8W, RCR05
S3	CAPACITOR COVER/SHIELD INTERLOCK SWITCH
R16	50M OHM +/-1%, MG720, CADDOCK, 6KV



ITEM 8 AND 9 BANANA PLUGS, INSIDE COVER / SHIELD.

LEAKAGE CURRENT TEST FIXTURE



PARTS LIST

FIND NO.	DESCRIPTION	QTY
1.	BANANA JACK	2
2.	CONNECTOR, ZIP (FOR 2.2 uFD CAPS)	2
3.	PCB, POLYIMIDE .062 THK	1

A SET OF BANANA JACKS WITH ALLIGATOR CLIP TO MEASURE PIGTAILED .022 uFD CAPS.

```
' DCLEAK.BAS
' Keithley 617 Elecrtometer
' Written in QuickBasic 4.5 by Neils Kruse
' 1/15/92

REM $INCLUDE: 'C:\GPIB-PC\QBDECL.BAS'   ' Use this line for the 8 bit card
'REM $INCLUDE: 'C:\AT-GPIB\QBDECL.BAS'  ' Use this line for the 16 bit card

DECLARE SUB gpiberr (msg$)
DECLARE SUB WriteData ()
DECLARE SUB ReadData ()
DECLARE SUB BufInput (StringVar$, Limit%)
DECLARE FUNCTION StrVal! (Txt$)

DIM SHARED rd AS STRING * 30
DIM SHARED BD AS INTEGER
DIM SHARED Serno AS INTEGER
DEF SEG = 0

CLS

rd$ = SPACE$(30)
INPUT ; "Erase capacitor DC leakage data? (Y/N)"; rd$
rd$ = UCASE$(rd$)

IF LEFT$(rd$, 1) = "Y" THEN            ' Erase "LEAK.DTA", DEFAULT IS NO
OPEN "LEAK.DTA" FOR OUTPUT AS #1
CLOSE #1
END IF
CLS

CALL SendIFC(0)                        ' Clear interface
IF IBSTA% < 0 THEN
CALL gpiberr("SendIFC error")
STOP
END IF

CLS
CALL IBFIND("DEV2", BD%)      'Assign the unit descripter to bd%
IF (BD% < 0) THEN
CALL gpiberr("Ibfind error")
STOP
END IF

CALL IBSRE(gpib0%, 1)
IF IBSTA% < 0 THEN
CALL gpiberr("IBSRE error")
STOP
END IF


CALL IBCLR(BD%)                 'Clear the device

WRT$ = "F1XZ1XZ0XC0X"
CALL IBWRT(BD%, WRT$)

LOCATE 3, 2
PRINT " What is the first serial number? ";
char$ = SPACE$(4)
StringVar$ = SPACE$(4)
```

```
PRINT " Press <ENTER> to test serial number " + STR$(Serno%)
PRINT "Or enter a different serial no. ";
COLOR 0, 7
PRINT SPACE$(4)

LOCATE 17, 1
COLOR 7, 0
PRINT "Or type " + "EXIT" + " to quit"

COLOR 0, 7
LOCATE 16, 33
a$ = SPACE$(4)
CALL BufInput(a$, 4)
COLOR 7, 0

IF VAL(a$) <> 0 THEN
Serno% = VAL(a$)
END IF

IF UCASE$(a$) = "EXIT" THEN
LOCATE 19, 3
rd$ = SPACE$(30)
INPUT ; "Exit program? (Y/N)"; rd$
rd$ = UCASE$(rd$)

IF LEFT$(rd$, 1) = "Y" THEN
EXIT DO
END IF

END IF

LOOP
OUT prtl%, 0

CLS
rd$ = SPACE$(30)
INPUT ; "Save data to floppy disk? (Y/N)"; rd$
rd$ = UCASE$(rd$)

IF LEFT$(rd$, 1) = "Y" THEN
CLS
r$ = SPACE$(1)
PRINT "Insert a floppy and press the letter"
INPUT ; "of the drive to be used"; r$
r$ = MID$(UCASE$(r$), 1, 1)
cmd$ = "COPY C:\LEAK.DTA " + r$ + ":"
LOCATE 4, 1
PRINT cmd$
SHELL (cmd$)

END IF

END

SUB BufInput (StringVar$, Limit%)
Length% = 0
StringVar$ = ""

'Loop waiting for input. Enter terminates the routine
WHILE char$ <> CHR$(13)
```

```
WHILE char$ <> CHR$(13)
char$ = INKEY$
IF char$ <> "" THEN
StringVar$ = StringVar$ + char$
PRINT char$;
END IF
WEND

Serno% = VAL(StringVar$)

CLS
LOCATE 3, 2
PRINT " Press <ENTER> to start the test"
DO
LOOP WHILE INKEY$ = ""

' Return printer port address

x = 1
prt1% = PEEK(1030 + 2 * x) + 256 * PEEK(1031 + 2 * x)
'PRINT HEX$(prt1%)

' Start of test loop

DO WHILE INKEY$ <> CHR$(27)
CLS
rd$ = ""

' Turn on HV with LPT1 data bit 0 (pin 2)
OUT prt1%, 1

t1! = TIMER
t2! = t1! + 1
WHILE TIMER < t2!
WEND

' Connect meter with LPT1 data bit 1 (pin 3)
OUT prt1%, 3

t1! = TIMER
t2! = t1! + 1
WHILE TIMER < t2!
WEND

CALL ReadData

LOCATE 3, 2
PRINT "Data for serial number " + STR$(Serno%)
PRINT
PRINT rd$, StrVal!(rd$)

CALL WriteData

' Disconnect meter with LPT1 data bit 1 (pin 3)
' and turn OFF HV with LPT1 data bit 0 (pin 2)
OUT prt1%, 0

Serno% = Serno% + 1

LOCATE 15, 2
```

```
char$ = INKEY$
IF char$ <> "" THEN
IF (Length% < Limit%) OR (char$ = CHR$(8)) THEN
SELECT CASE char$
CASE " " TO "~"      ' Other printable character
StringVar$ = StringVar$ + char$
PRINT char$;
Length% = Length% + 1
CASE CHR$(8)         ' Backspace was entered
IF Length% <> 0 THEN
Length% = Length% - 1
StringVar$ = LEFT$(StringVar$, Length%)
CurrX% = CSRLIN
CurrY% = POS(0) - 1
LOCATE CurrX%, CurrY%
PRINT " "
LOCATE CurrX%, CurrY%
END IF
END SELECT
ELSE
PLAY "o1A132"
END IF
END IF
WEND


END SUB

'==========================================================================
'                          Subroutine GPIBERR
'  This subroutine will notify you that a NI-488 function failed by printing
'  an error message.  The status variable IBSTA% will also be printed
'  in hexadecimal along with the mnemonic meaning of the bit position.
'  The status variable IBERR% will be printed in decimal along with the
'  mnemonic meaning of the decimal value.  The status variable IBCNT% will
'  be printed in decimal.
'
'  The NI-488 function IBONL is called to disable the hardware and software.
'
'  The STOP command will terminate this program.
'==========================================================================
'
SUB gpiberr (msg$) STATIC

  PRINT msg$

  PRINT "ibsta = &H"; HEX$(IBSTA%); " <";
  IF IBSTA% AND EERR THEN PRINT " ERR";
  IF IBSTA% AND TIMO THEN PRINT " TIMO";
  IF IBSTA% AND EEND THEN PRINT " END";
  IF IBSTA% AND SRQI THEN PRINT " SRQI";
  IF IBSTA% AND RQS THEN PRINT " RQS";
  IF IBSTA% AND CMPL THEN PRINT " CMPL";
  IF IBSTA% AND LOK THEN PRINT " LOK";
  IF IBSTA% AND RREM THEN PRINT " REM";
  IF IBSTA% AND CIC THEN PRINT " CIC";
  IF IBSTA% AND AATN THEN PRINT " ATN";
  IF IBSTA% AND TACS THEN PRINT " TACS";
  IF IBSTA% AND LACS THEN PRINT " LACS";
  IF IBSTA% AND DTAS THEN PRINT " DTAS";
```

```
    IF IBSTA% AND DCAS THEN PRINT " DCAS";
    PRINT " >"

    PRINT "iberr = "; IBERR%;
    IF IBERR% = EDVR THEN PRINT " EDVR <DOS Error>"
    IF IBERR% = ECIC THEN PRINT " ECIC <Not CIC>"
    IF IBERR% = ENOL THEN PRINT " ENOL <No Listener>"
    IF IBERR% = EADR THEN PRINT " EADR <Address error>"
    IF IBERR% = EARG THEN PRINT " EARG <Invalid argument>"
    IF IBERR% = ESAC THEN PRINT " ESAC <Not Sys Ctrlr>"
    IF IBERR% = EABO THEN PRINT " EABO <Op. aborted>"
    IF IBERR% = ENEB THEN PRINT " ENEB <No GPIB board>"
    IF IBERR% = EOIP THEN PRINT " EOIP <Async I/O in prg>"
    IF IBERR% = ECAP THEN PRINT " ECAP <No capability>"
    IF IBERR% = EFSO THEN PRINT " EFSO <File sys. error>"
    IF IBERR% = EBUS THEN PRINT " EBUS <Command error>"
    IF IBERR% = ESTB THEN PRINT " ESTB <Status byte lost>"
    IF IBERR% = ESRQ THEN PRINT " ESRQ <SRQ stuck on>"
    IF IBERR% = ETAB THEN PRINT " ETAB <Table Overflow>"

    PRINT "ibcnt = "; IBCNT%

  ' Call the IBONL function to disable the hardware and software.

    CALL IBONL(brd0%, 0)

    STOP

  END SUB

  SUB ReadData

  WRT$ = "B0XG1X"
  CALL IBWRT(BD%, WRT$)

  rd$ = SPACE$(30)
  CALL IBRD(BD%, rd$)

  END SUB

  DEFINT A-Z
  FUNCTION StrVal! (Txt$) STATIC

   ' Converts a string to a number. Must be a + or - in front of exponent.
   ' The range of valid numbers is -9.99999E+9 to +9.99999E+9.
   StrVal! = 0
   Temp$ = ""
   Power! = 1
   Epos% = 0

   'Find the position of the "e"

   IF INSTR(Txt$, "e") > 0 OR INSTR(Txt$, "E") > 0 THEN
  Epos% = INSTR(Txt$, "e") OR INSTR(Txt$, "E")
   ELSE
  StrVal! = -8.88888E+08
  EXIT FUNCTION
   END IF

   ' If first character is "+" then loose it
```

```
 ' Trim off any characters after the "e"

 IF LEFT$(Txt$, 1) = "+" THEN
Temp$ = MID$(Txt$, 2, Epos% - 1)
 ELSE
Temp$ = MID$(Txt$, 1, Epos% - 1)
 END IF


 ' Find the exponent value

 x% = VAL(MID$(Txt$, Epos% + 2, 2))

 ' Find the exponent sign and calculate the power

 IF MID$(Txt$, Epos% + 1, 1) = "+" THEN
FOR J = 1 TO x%
Power! = Power! * 10
NEXT J
 ELSE
FOR J = 1 TO x%
Power! = Power! * .1
NEXT J
 END IF

 StrVal! = Power! * (VAL(Temp$))

END FUNCTION

DEFSNG A-Z
SUB WriteData
OPEN "LEAK.DTA" FOR APPEND AS #1
WRITE #1, STR$(Serno%), StrVal(rd$)
CLOSE #1
END SUB
```

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

	Pages
1.0 Components	
1.2 Capacitors	
1.2.3 Crowbar Test Procedure	1.2-32 to 1.2-41

CAPACITOR CROWBAR TEST PROCEDURE

1. TEST EQUIPMENT

   A. Capacitor crowbar test fixture

   B. HVPS, Sorensen 230-6P-R&D

   C. Fluke 8810A Digital Multimeter with 1000 to 1 voltage divider 80F-15

   D. Regulated 0-30Vdc @200mA power supply

   E. Regulated 0-10Vdc @200mA power supply

   F. PC Computer (controls test fixture via J1 connector)

2. HOOK UP AND PREALIGNMENT

   A. Test fixture switch "LVPS" S1 to "OFF"

   B. High voltage power supply power switch to "OFF"

   C. Pre-align the LVPS's to +24Vdc +/-1% and +5Vdc +/-1%

   D. Shut off LVPS's and hook up to test fixture

   E. Hook up the HVPS to the test fixture. Turn on the HVPS and pre-align output voltage to +2000Vdc +/-1% via TP1 using the DMM with the 1000:1 HV divider.

   F. Place the two LVPS power switches to "ON"

   G. Place the test fixture "LVPS" switch S1 to "ON"

   H. Place a temporary jumper from the test fixture connector pin "J1-Pin2" to the positive terminal of the +5Vdc LVPS. The "HV ENABLED" LED "DS1" should illuminate indicating the closure of "K1" HV relay. (The shield must be latched to activate interlock switch).

   I. Place the 1000:1 divider probe into TP2. Measure the internal regulator voltage. It should read +1000Vdc +/-1% - if not, adjust R8 (through hole at side of chassis).

   J. Place the "LVPS" Switch "S1" to "OFF." Remove the temporary jumper.

   K. Place the HVPS power switch to "OFF"

   L. Place the 1000:1 divider probe into TP1

   M. Plug the computer interface connector into the test fixture computer interface connector "J1"

3. TEST PROCEDURE (Automated)

A. Place the computer in the standby-ready mode

B. Place the LVPS power switches to "ON"

C. Place the HVPS power switch to "ON." The Fluke DMM should ready +2.000Vdc +/-1%.

D. Place the "LVPS" switch "S1" to "ON." The "HV ENABLED" or the "ARC TES" LEDS should not be illuminating.

E. Activate the computer program. Follow the instructions. (The HV will be applied first and this will be evidenced by the illumination of the "HV ENABLED" LED. Two seconds later, the arc testing will commence and this will be evidenced by the illumination of the "ARC TEST" LED). (At the end of the arc test, the "ARC TEST" LED will extinguish then, the "HV ENABLED" LED will extinguish). (The shield must be latched to close the interlock switch thus permitting HV operation).

F. At the conclusion of the testing: Place the "LVPS" Switch "S1" to "OFF," place the two LVPS Pwr Switches to "OFF," place the HVPS Pwr Switch to "OFF."

4. TEST PROCEDURE (Manual)

A. Place all switches on the capacitor crowbar test fixture to "OFF" (lower position)

B. Place the LVPS power switches to "ON"

C. Place the HVPS power switch to "ON." The Fluke DMM should read +2.150Vdc +/01%.

D. Place the "LVPS" Switch "S1" on the test fixture to "ON." The "HV ENABLED" or the "ARC TEST" LEDS should not be illuminated.

E. Open the shield latch and raise the shield cover.

F. Insert (or replace) the UUT capacitor into the "ZIF" (zero insertion force) connector. Turn the two levers "CCW" to "UNLOCK" the connector and turn the two levers "CW" to "LOCK" the connector.

G. Lower the shield cover and lock the shield latch. (The shield latch enables the HV interlock switch which enables operation).

H. Place the "HV ENABLED" Switch "S3" on the test fixture to "ON." The "HV ENABLED" LED should be illuminating.

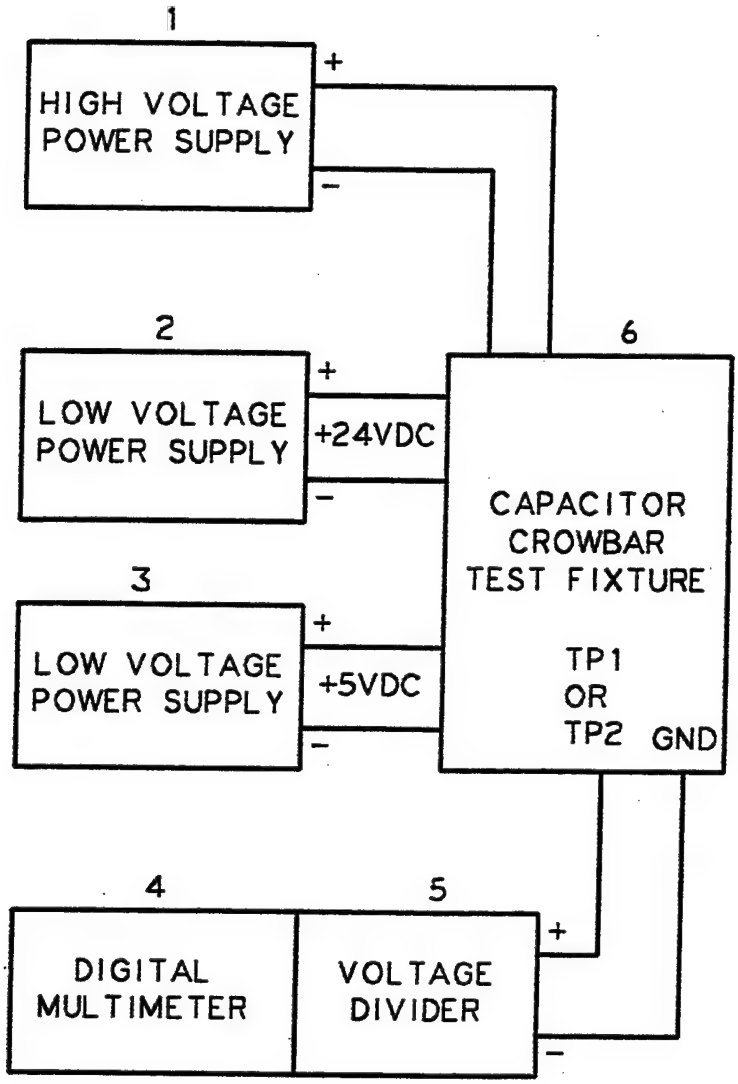
I. Wait "ONE SECOND" then, place the "ARC TEST" Switch "S4" on the test fixture to "ON." The "ARC TEST" LED should be illuminating. The test is now in progress. The testing should be "VERIFIED" by the pulsating of the current meter needle on the HVPS. After 100 arc pulses the "ARC TEST" LED will cease to illuminate, indicating the end of the test.

J. Place the "ARC TEST" Switch "S4" on the test fixture to "OFF"

K. Wait "ONE SECOND" then, place the "HV ENABLED" Switch "S3" on the test fixture to "OFF." The "HV ENABLED" LED will extinguish.

L. Repeat steps "E" through "K" to test more UUT capacitors.

M. If no more UUT capacitors are to be tested then, place the "LVPS" Switch "S1" on the test fixture to "OFF." Place the HVPS Power Switch to "OFF." Place the LVPS Power Switches to "OFF."

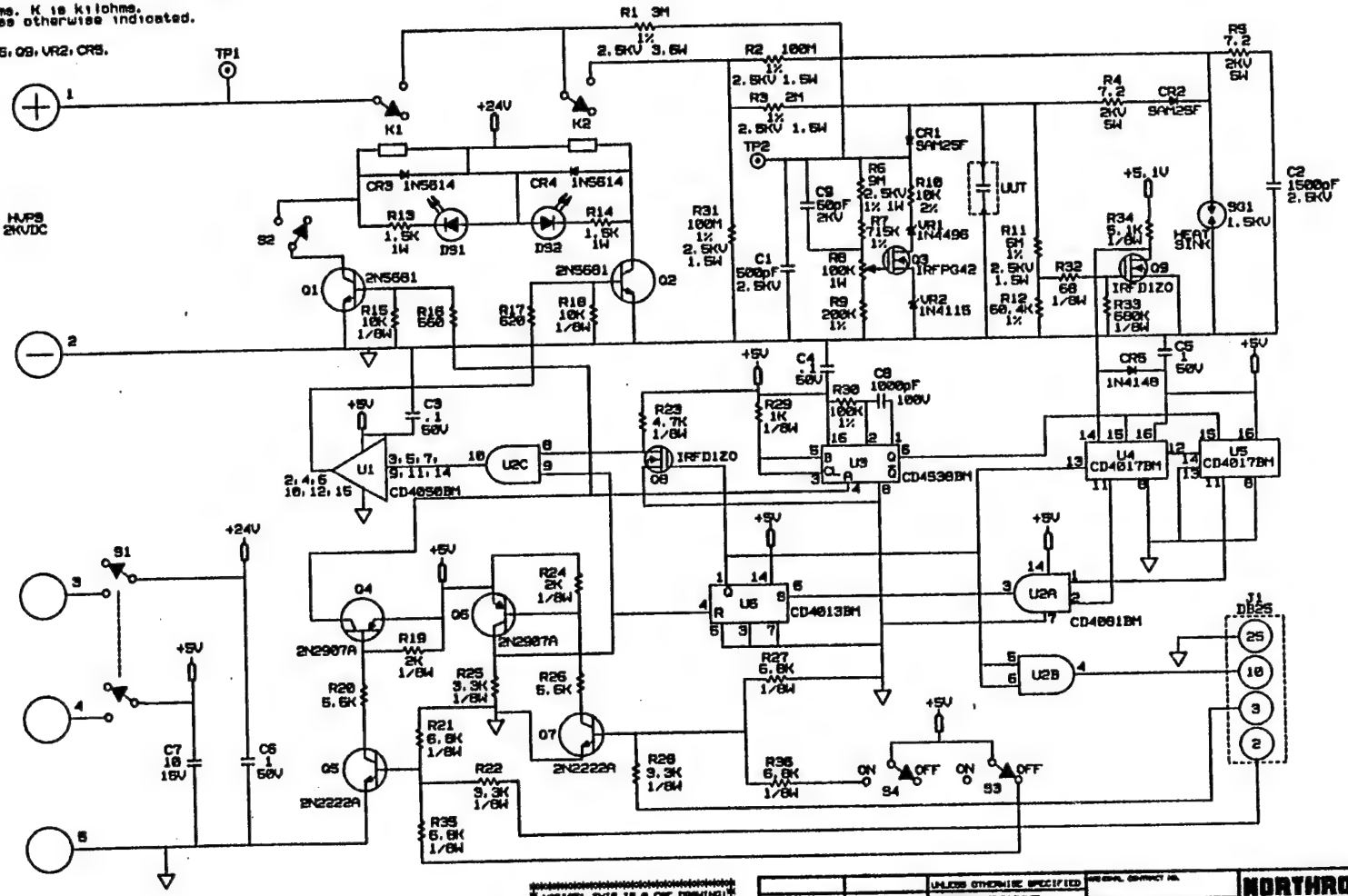


1. REGULATED HIGH VOLTAGE POWER SUPPLY, SORENSEN 230-6P-R&D.
2. REGULATED LOW VOLTAGE POWER SUPPLY, 0 - 30VDC @ 200 MA.
3. REGULATED LOW VOLTAGE POWER SUPPLY, 0 -10VDC @ 200 MA.
4. DIGITAL MULTIMETER, FLUKE 8810A (SET TO VDC).
5. 1000 : 1 VOLTAGE DIVIDER, FLUKE 80F-15.
6. CAPACITOR CROWBAR TEST FIXTURE, SEE ATTACHED SCHEMATIC AND PARTS LIST.

THE DIMENSIONS AND TOLERANCING PRACTICE USED ON THIS DRAWING IS IN ACCORDANCE WITH ANSI Y14.5M-1982

/home1/kruse/CPI/SITE.INRUSH.1.1
LAST_MODIFIED=Mon Nov 20 15:08:49 1995

Notes:
1. All capacitances are uF unless otherwise indicated.
2. All resistances are Ohms. K is kilohms. Tolerances are 5% unless otherwise indicated.
3. Highest Ref Desig: R36, C9, SG1, J1, D92, S4, U6, Q9, VR2, CR5.



NOTICE! THIS IS A CRC DRAWING! IF MANUAL CHANGES ARE MADE, THIS DRAWING SHALL NOT BE RELEASED UNTIL THE CRC DATA-BASE HAS BEEN UPDATED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED

DRAWN N. KRUSE

NORTHROP

SCHEMATIC, CAPACITOR CROWBAR TEST FIXTURE

SIZE D | CAGE CODE 26916

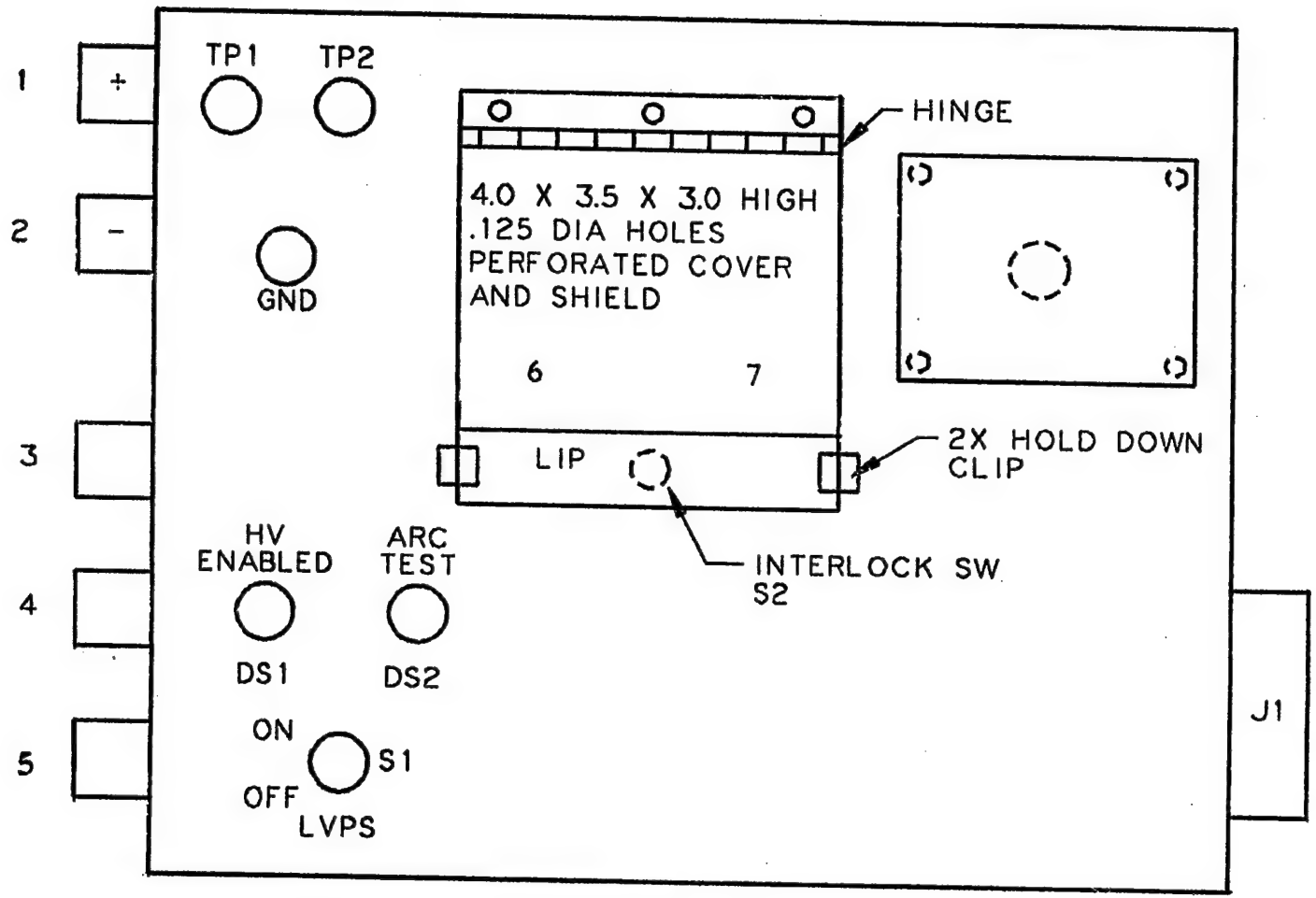
SCALE: NONE | SHEET 1 OF 1

PARENTHETICAL DATA MARKED WITH AN ASTERISK (*) IS REGULAR TO A PRIOR MANUFACTURER. IT DOES NOT TAKE PRECEDENCE OVER ANY OTHER DATA ON THIS DRAWING AND IS NOT CONTRACTUALLY BINDING ON EITHER THE CONTRACTOR OR THE GOVERNMENT.

CAPACITOR CROWBAR TEST FIXTURE

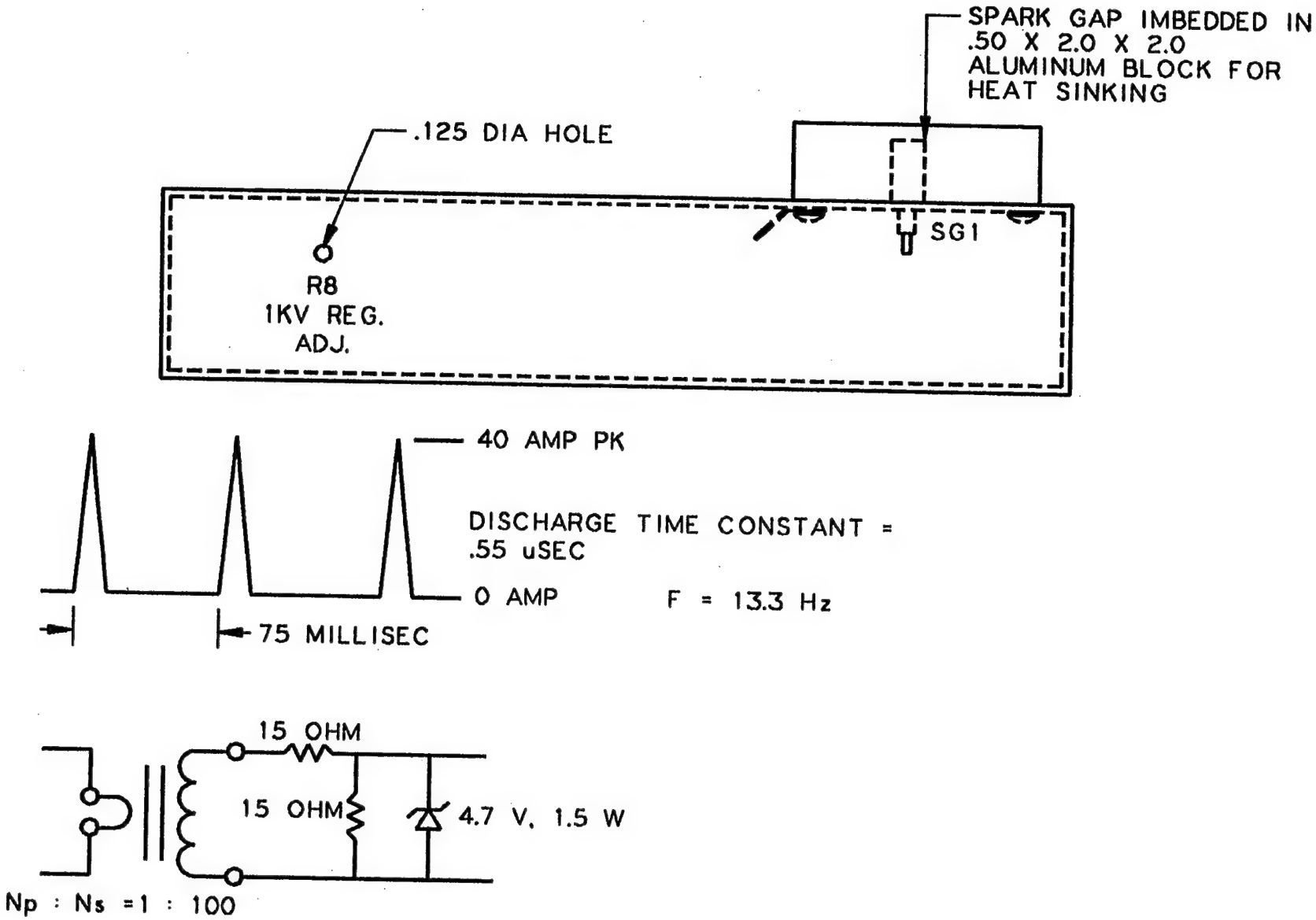
S1	DPDT TOGGLE SWITCH, 115VAC, 1A
U1	CD4050BM HEX NON-INVERTING BUFFER, NATIONAL SEMI.
U2	CD4081BM QUAD 2-INPUT AND GATE BUFFERED, NATL. SEMI.
U3	CD4538BM DUAL MONOSTABLE MULTIVIBRATOR, NATIONAL SEMI.
U4,5	CD4017BM DECADE COUNTER, NATIONAL SEMI.
U6	CD4013BM DUAL D FLIP-FLOP NATIONAL SEMI.
Q1,2	2N5681, TO-5 WITH RADIATOR, MOTOROLA
Q3	IRFPG42, 1000V, 3.9A, INT. RECT. (ALT. MOTOROLA MTM/N100)
Q4,6	2N2907A, TO-18
Q5,7	2N2222A, TO-18
Q8,9	IRFD120, 100V, INT. RECT.
R19,24	2K OHM +/-5%, 1/8W, RCR05
R20,26	5.6K OHM +/-5%, 1/4W, RCR07
R21,27,35,36	6.8K OHM +/-5%, 1/8W, RCR05
R22,28,25	3.3K OHM +/-5%, 1/8W, RCR05
R23	4.7K OHM +/-5%, 1/8W, RCR05
VR1	IN4496, 200V, 1.5W, UNITRODE
VR2	IN4115, 22V +/-5%, MOTOROLA
S3,4	SPDT SWITCH, 115VAC, 1 AMP
CR1,2	SAM25F, SSDI, Ipk 60A, Iavg-1.5A, PIV-2.5KV
CR3,4	IN5614, 200V, 1A, UNITRODE
CR5	IN4148, UNITRODE
S2	COVER/SHIELD INTERLOCK SWITCH, 28VDC, 1A
R1	3M OHM +/-1%, 3.6W, 2.5KV, CADDOCK MG735
R2	100N IGN +/-1%, 1.5W, 2.5KV, CADDOCK MG716
R3	2M OHM +/-1%, 1.5W, 2.5KV, CADDOCK MG716
R4,5	7.2 OHM +/-1%, 5W, 2KV, CADDOCK MS260
R6	9M OHM +/-1%, 1W, 2.5KV, CADDOCK MG710
R7	715K OHM +/-1%, RNC60H
R8	100K OHM +/-5%, 1W CERMET TRIMMER, BOURNS 3252W
R9	200K OHM +/-1%, RNC55H
R10	10K OHM +/-2%, 1/4W, RLR07
R11	6M OHM +/-1%, 1.5W, 2.5KV, CADDOCK MG716
R12	60.4K OHM +/-1%, RNC55
R13,14	1500 OHM +/-5%, 1W, RCR32
R15,18	10K OHM +/-5%, 1/8W, RCR05
R16	560 OHM +/-5%, 1/4W, RCR07
R34	5.1K OHM +/-5%, 1/8W, RCR05
R29	1K OHM +/-5%, 1/8W, RCR05
R32	58 OHM +/-5%, 1/8W, RCR05

R17	620 OHM +/-5%, 1/4W, RCR07
R33	680K OHM +/-5%, 1/8W, RCR05
R30	100K OHM +/-1%, RNC55H
R31	100M OHM +/-1%, 1.5W, 2.5KV, CADDOCK MG716
C1	500pFd +/-5%, 2.5KV
C9	50pFd +/-5%, 2KV
C2	1500pFd +/-5%, 2.5KV
C3,4	0.1uFd +/-10%, 50V, CKR05
C5,6	1.0uFd +/-10%, 50V, CKR06
C7	10uFd +/-10%, 15v, CSR13
C8	1000pFd +/-5%, 100v, CKR05
DS1,2	LED, RED (1.2V @15MA)
SG1	039-000913-003, 1500V ELECT. SURGE ARRESTOR, HEAT SUNK
J1	DB25 FEMALE CONNECTOR (25 PIN D-TYPE CONNECTOR)



ITEM 6 AND 7 BANANA PLUGS, INSIDE COVER / SHIELD.

CAPACITOR CROWBAR



CAPACITOR CROWBAR

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

	Pages
1.0 Components	
1.2 Capacitors	
1.2.4 Inrush Current Test Procedure	1.2-42 to 1.2-51

INRUSH CURRENT TEST PROCEDURE

1. TEST EQUIPMENT

   A. Inrush current test fixture

   B. Regulated power supply, Lambda LPD-425A-FM (series stack the two output voltages)

   C. Regulated 0-20Vdc @100mA power supply

   D. Regulated o-10Vdc @200mA power supply

   E. Digital Voltmeter, 0-600Vdc

   F. Four channel, storage oscilloscope with 10:1 probe

2. HOOK-UP AND PRE-ALIGNMENT

   A. All test fixture switches to "OFF"

   B. HV power supply power switch to "OFF"

   C. Pre-align the two LVPS's to +5.0Vdc +/-1% and -10.0Vdc +/-1%

   D. Shut off LVPS's and hook-up to test fixture

   E. turn on HVPS. Current limit to 100mA. Pre-align the output voltage to -400Vdc +/-1% (each output set to 200Vdc).

   F. Shut off HVPS and hook-up to test fixture

   G. Connect a BNC coaxial cable from the current transformer to the oscilloscope

   H. Set oscilloscope scales for 0.5V/CM and 1MSEC/CM

   I. Plug the "ZIF" connector/adapter into the test fixture "UUT" output terminals.

3. TEST PROCEDURE

   A. All test fixture switches to "OFF"

   B. One jumper cable should be removed from the test fixture. Two should be in place (one with the current transformer and one without)

   C. turn on the two LVPS's (+5.0Vdc +/-1% and -10.0Vdc +/-1%).

   D. turn on the HVPS (-400Vdc +/-1%).

   E. Plug in a "UUT" capacitor into the "ZIF" connector. Secure the capacitor in the connector by means of the two levers (CW).

F. Place the "LVPS" PWR switch (on test fixture) to "ON"

G. Depress the "RESET" switch momentarily

H. Place the "HV" Power Switch (on test fixture) to "ON"

I. Place the "OPR" switch to "ON." The illumination of the yellow LED light indicates that the capacitor is being "CURRENT SURGE" tested.

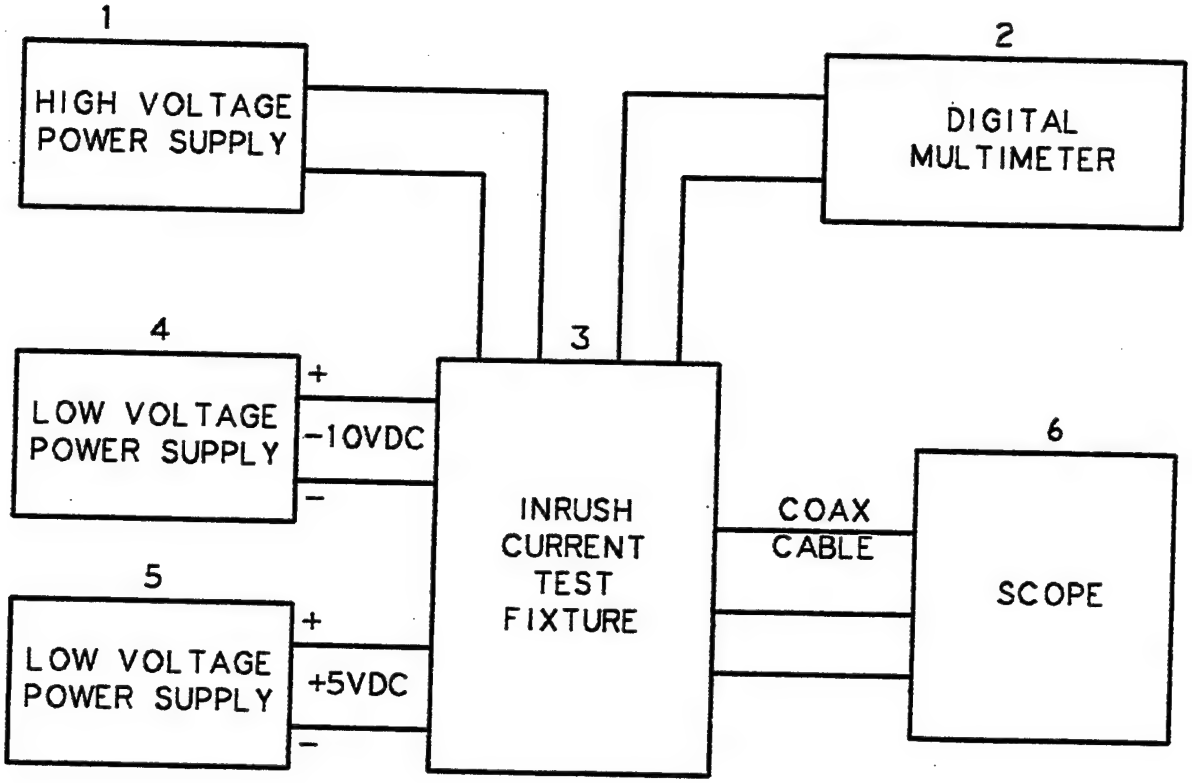
J. When the yellow LED light extinguishes, it indicates the total number of "CURRENT SURGE" pulses have been completed. Place the "OPR" Switch to "OFF"

K. Place the "HV" PWR switch (on the fixture) to "OFF"

L. Replace the "UUT" capacitor with another "UUT" capacitor. Release the capacitor in the "ZIF" connector by means of the two levers (CCW).

M. Repeat steps "G" through "L"

N. At the conclusion of the "UUT" testing, place all test fixture switches to "OFF" and all power supply power switches to "OFF"



1. REGULATED HIGH VOLTAGE POWER SUPPLY, LAMDA LPD-425A-FM. (SERIES STACK THE TWO OUTPUT VOLTAGES).

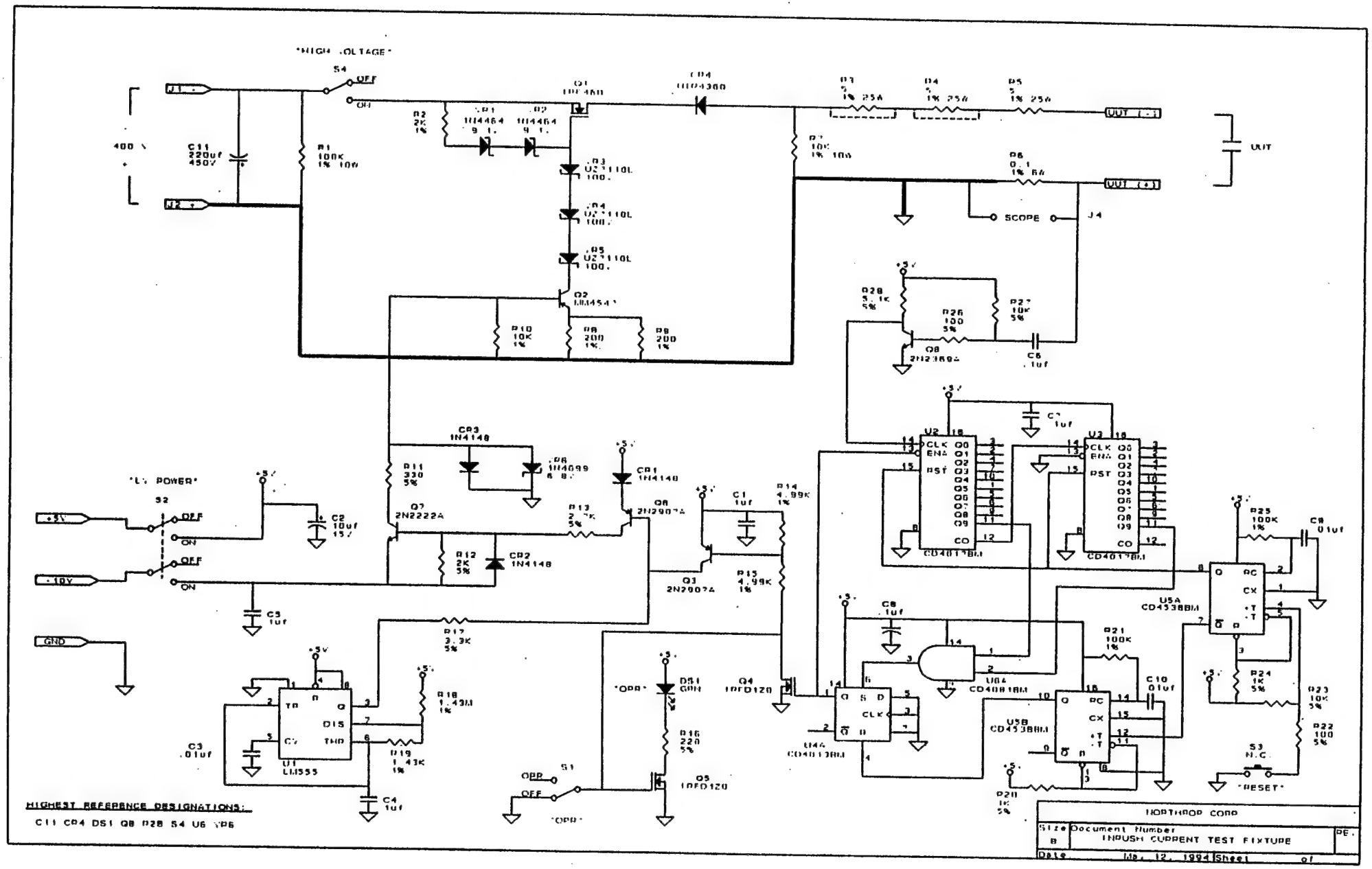
2. DIGITAL MULTIMETER, FLUKE 8600A (SET TO VDC).

3. INRUSH CURRENT TEST FIXTURE. SEE ATTACHED SCHEMATIC AND PARTS LIST.

4. REGULATED LOW VOLTAGE POWER SUPPLY, 0 - 20VDC @ 100 MA.

5. REGULATED LOW VOLTAGE POWER SUPLY, 0 - 10VDC @ 200 MA.

6. STORAGE OSCILLOSCOPE, TEKTRONIX 7834 WITH 7A26 AND 7B92A PLUG-INS AND X10 VOLTAGE PROBES.


"HIGH VOLTAGE"
S4
OFF
ON
J1
J2
400 V
C11
220uf
450V
R1
100K
1% 10W
R2
2K
1%
CR1
1N4464
CR2
1N4464
Q1
IRF460
CR4
1N4380
R3
5
1% 25W
R4
5
1% 25W
R5
5
1% 25W
VOUT (-)
VOUT (+)
VOUT
R7
10K
1% 10W
R6
0.1
1% 6W
SCOPE
J4
CR3
U2S110L
100V
CR4
U2S110L
100V
CR5
U2S110L
100V
Q2
IRF454
R10
10K
1%
R8
200
1%
R9
200
1%
+5V
R28
5.1K
5%
R26
100
5%
R27
10K
5%
Q8
2N2369A
C6
.1uf
C7
1uf
U2
CD4017BM
U3
CD4017BM
CR3
1N4148
CR6
1N4099
6.8V
R11
330
5%
Q7
2N2222A
R12
2K
5%
CR2
1N4148
R13
2.7K
5%
CR1
1N4148
Q6
2N2907A
Q3
2N2907A
C1
1uf
R14
4.99K
1%
R15
4.99K
1%
"L" POWER"
S2
+5V
-10V
GND
C2
10uf
15V
C5
1uf
R17
3.3K
5%
U1
LM555
R18
1.43M
1%
R19
1.43K
1%
C3
.01uf
C4
1uf
"OPR"
DS1
GRN
R16
220
5%
Q5
IRFD120
S1
OPR
OFF
Q4
IRFD120
U4A
CD4013BM
U4B
CD4081BM
C8
.1uf
R21
100K
1%
C10
.01uf
U5A
CD4538BM
U5B
CD4538BM
R20
1K
5%
R25
100K
1%
C9
.01uf
R24
1K
5%
R23
10K
5%
R22
100
5%
S3
N.C.
"RESET"
HIGHEST REFERENCE DESIGNATIONS:
C11 CR4 DS1 Q8 R28 S4 U6 VR6
NORTHROP CORP
Size
B
Document Number
INRUSH CURRENT TEST FIXTURE
Date
Mar. 12, 1994
Sheet
of

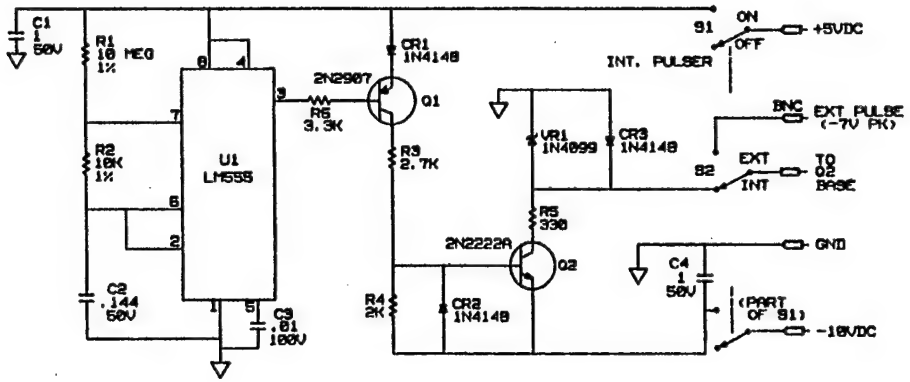
DESIGNATION	PART# / VALUE	TYPE / DESCRIPTION
C1,C5	1.0uf 10% 50V	CKR06 CAPACITOR
C2	10uf 10% 15V	CSR13 CAPACITOR
C3	.01uf 10% 50V	CKR05 CAPACITOR
C4	1.0uf 1% 50V	POLYSULFONE CAPACITOR
C6,C7,C8	.1uf 10% 50V	CKR05 CAPACITOR
C9,C10	.01uf 10% 50V	CKR05 CAPACITOR
C11	220uf 10% 450V	SPRAGUE 36D CAPACITOR
CR1,CR2,CR3	1N4148	DIODE
CR4	UTR4360	UNITRODE RECTIFIER
DS1	559-0201	DIALITE GREEN LED
Q1	IRF460	INT. RECT. TRANSISTOR
Q2	MM4547	MOTOROLA TRANSISTOR
Q3,Q6	2N2907A	TRANSISTOR
Q4,Q5	IRFD1Z0	INT. RECT. TRANSISTOR
Q7	2N2222A	TRANSISTOR
Q8	2N2369A	TRANSISTOR
R1	100K 1% 10W	DALE RS-10 RESISTOR
R2	2K 1% .1W	RNC55 RESISTOR
R3,R4,R5	5 1% 25W	DALE ENH-25 RESISTOR
R6	.1 1% 6W	CADDOCK MV261 RESISTOR
R7	10K 1% 10W	DALE ESN RESISTOR
R8,R9	200 1% .125W	RNC60 RESISTOR
R10	10K 1% .05W	RNC50 RESISTOR
R11	330 5% .25W	RCR07 RESISTOR
R12	2K 5% .125W	RCR05 RESISTOR
R13	2.7K 5% .25W	RCR07 RESISTOR
R14,R15	4.99K 1% .05W	RNC50 RESISTOR
R16	220 5% .25W	RCR07 RESISTOR
R17	3.3K 5% .25W	RCR07 RESISTOR
R18	1.43M 1% .1W	RNC55 RESISTOR
R19	1.43K 1% 1W	RNC55 RESISTOR
R20,R24	1K 5% .125W	RCR05 RESISTOR
R21,R25	100K 1% .05W	RNC50 RESISTOR
R22,R26	100 5% .125W	RCR05 RESISTOR
R23,R27	10K 5% .125W	RCR05 RESISTOR
R28	5.1K 5% .125W	RCR05 RESISTOR
S1	MTA-106D	ALCO SPDT TOGGLE SWITCH
S2	MTA-206N	ALCO DPDT TOGGLE SWITCH
S3	MPA-106F	ALCO SPDT MOM. SWITCH
S4	80600-268	ARROW HART DPST SWITCH
U1	LM555CN	INTEGRATED CIRCUIT
U2,U3	CD4017BM	INTEGRATED CIRCUIT
U4	CD4013BM	INTEGRATED CIRCUIT
U5	CD4538BM	INTEGRATED CIRCUIT
U6	CD4081BM	INTEGRATED CIRCUIT
VR1,VR2	IN4464 9.1V 5% 1.5W	ZENER DIODE
VR3,VR4,VR5	UZ7110L 100V 5% 6W	UNITRODE ZENER DIODE
VR6	IN4099 6.8V 5% .25W	ZENER DIODE

THE DIMENSIONING AND TOLERANCING PRACTICE USED ON THIS DRAWING IS IN ACCORDANCE WITH ANSI Y14.5M-1982

/home1/kruse/CPI/SITB.INRUSH.1.2
LAST_MODIFIED=Fri Nov 17 14:26:46 1995

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	XA		951114	

Notes:
1. All capacitances are uF unless otherwise indicated.
2. All resistances are Ohms. K is kilohms.
   Tolerances are 5% unless otherwise indicated.
3. Highest Ref Desgn:
   C4, R5, CR3, VR1, Q2, U1, S2.



NOTICE: THIS IS A CAD DRAWING! IF MANUAL CHANGES ARE MADE, THIS DRAWING SHALL NOT BE RELEASED UNTIL THE CAD DATA-BASE HAS BEEN UPDATED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AFTER FINISHING
TOLERANCES ON
3 PLACE DECIMAL ± .010
2 PLACE DECIMAL ± .030
ANGLES ± 30 MIN
DIMENSIONS, TOLERANCES APPLY TO EACH SIDE
PARTS SHALL BE CLEAN AND FREE OF BURRS AND SHARP EDGES
ALL SURFACES 125 √ AFTER FINISHING
CM

DRAWN N. KRUSE

NORTHROP Northrop Corporation Electronics Systems Division Rolling Meadows Site Operations Rolling Meadows, Illinois

SCHEMATIC, PULSER
FOR INRUSH CURRENT
TEST FIXTURE

SIZE D | CAGE CODE 26916 | DWG NO.

SCALE: NONE | SHEET 1 OF 1

PARENTHETICAL DATA MARKED WITH AN ASTERISK (*) IS PECULIAR TO A PRIOR MANUFACTURER. IT DOES NOT TAKE PRECEDENCE OVER ANY OTHER DATA ON THIS DRAWING AND IS NOT CONTRACTUALLY BINDING ON EITHER THE CONTRACTOR OR THE GOVERNMENT.

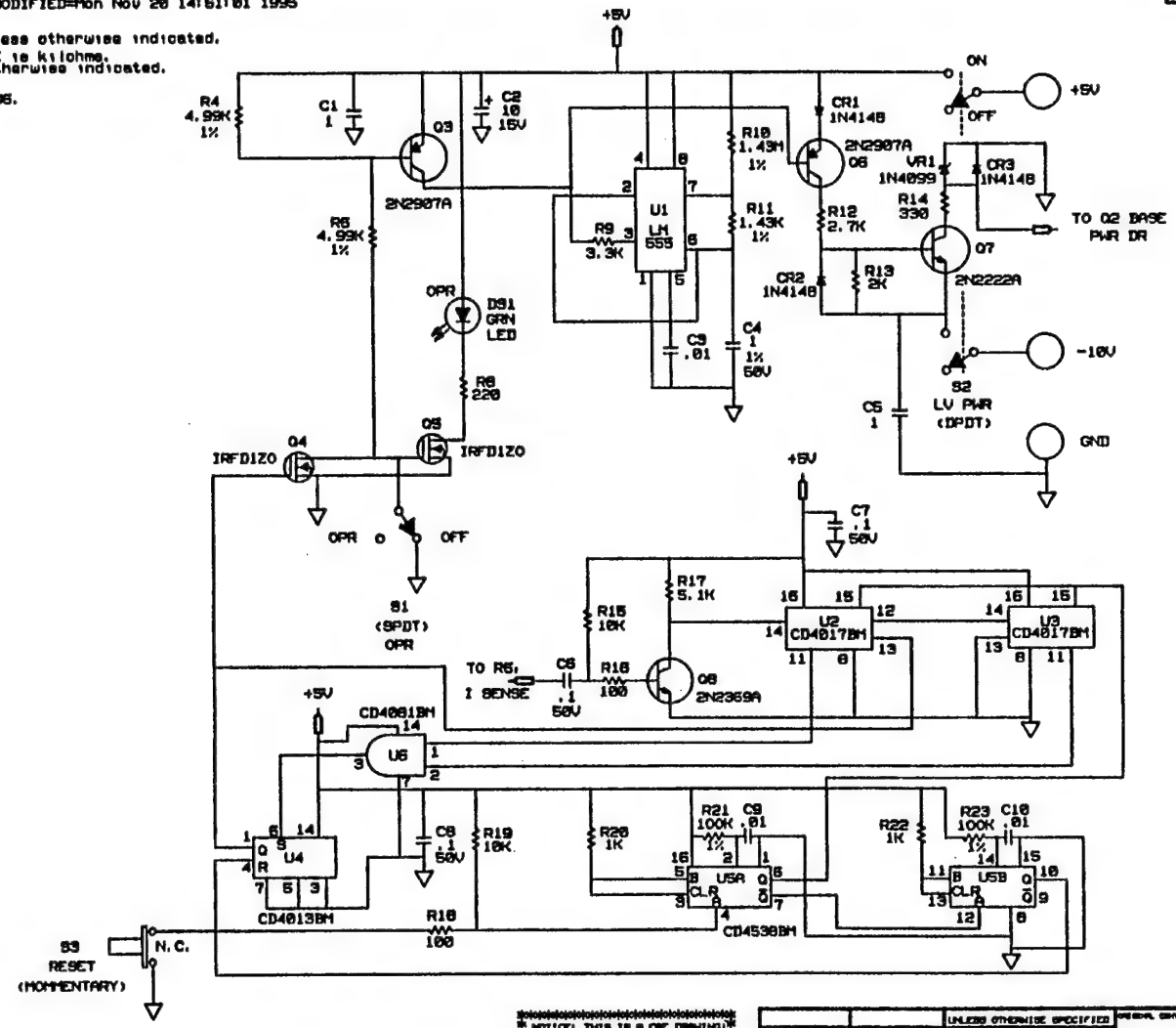
PULSER FOR INRUSH CURRENT TEST FIXTURE

C1,4	1uFd +/-10%, 50V, CKR06
C2	0.144uFd +/-2%, 50V, CKR05 (MULTIPLE CKR05s)
C3	0.01uFd +/-10%, 100V, CKR05
R1	10M OHM +/-1%, RNC65H
R2	10K OHM +/-1%, RNC50H
R3	2.7K OHM +/-5%, RCR-07
R4	2K OHM +/-5%, RCR05
R5	330 OHM +/-5%, RCR07
R6	3.3K OHM +/-5%, RCR05
CR1,2,3	IN4148
VR1	6.8V +/-5%, IN4099, 250 MILLIWATTS, MOTOROLA
Q1	2N2907A, TO-18
Q2	2N2222A, TO-18
U1	LM555, NATIONAL SEMICONDUCTOR, 8 PIN DIP
S1	DPDT, 115VAC, 1A
S2	SPDT, 115VAC, 1A

THE DIMENSIONING AND TOLERANCING PRACTICE USED ON THIS DRAWING IS IN ACCORDANCE WITH ANSI Y14.5M-1982

/home1/kruse/CPI/SITB.INRUSH.1.3
LAST_MODIFIED=Mon Nov 20 14:51:01 1995

Notes:
1. All capacitances are uF unless otherwise indicated.
2. All resistances are Ohms. K is kilohms. Tolerances are 5% unless otherwise indicated.
3. Highest Ref Degn: R23, C10, DS1, CR3, VR1, Q8, S3, U6.



NOTICE: THIS IS A CAE DRAWING! IF MANUAL CHANGES ARE MADE, THIS DRAWING SHALL NOT BE RELEASED UNTIL THE CAE DATA-BASE HAS BEEN UPDATED.

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	XA		951106	

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED

NORTHROP

DRAWN N. KRUSE

SCHEMATIC, INRUSH CURRENT CONTROL
TEST FIXTURE

SIZE D | CAGE CODE | DWG NO. 26916

SCALE: NONE | SHEET 1 OF 1

PARENTHETICAL DATA MARKED WITH AN ASTERISK (*) IS REGULAR TO A PRIOR MANUFACTURER. IT DOES NOT TAKE PRECEDENCE OVER ANY OTHER DATA ON THIS DRAWING AND IS NOT CONTRACTUALLY BINDING ON EITHER THE CONTRACTOR OR THE GOVERNMENT.

INRUSH CURRENT CONTROL TEST FIXTURE

R4	4.99K +/-1% RNC50H
R6	4.99K +/-1% RNC50H
R8	220 +/-5% RCR07
R9	3.3K +/-5% RCR07, 1/4W
R10	1.43M +/-1% RNC55H
R11	1.43K +/-1% RNC55H
R12	2.7K +/-5% RCR07
R13	2K +/-5% RCR05
R14	330 +/-5% RCR07
R15,19	10K +/-5% RCR05
R16,18	100 +/-5% RCR05
R17	5.1K +/-5% RCR05
R20,22	1K +/-5% RCR05
R21,23	100K +/-1% RNC50H
C1,5	1.0uFd +/-10% CKR06
C2	10uFd +/-10% 15V CSR13
C3	.01uFd +/-10% CKR05
C4	1.0uFd +/-10% 50V Polysulfone
C6,7,8	0.1uFd +/-10% 50V CKR05
C9,10	.01uFd +/-10% CKR05
DS1	GREEN LED
CR1,2,3	IN4148
VR1	6.8V +/-5%, 250MW, IN4099, MOTOROLA
Q7	2N2222A TO-18
Q3,6	2N1907A TO-18
Q4,5	IRFD1ZO, PLASTIC, INT RECT.
Q8	2N2369A TO-18
S1	115V, 1A, SPDT
S2	115V, 1A, DPDT
S3	115V, 1A, MOMENTARY PUSH BUTTON SPDT
U1	LM555 8 PIN DIP NATIONAL
U2,3	CD 40176BM DECADE COUNTER NATIONAL
U4	CD 4013BM DUAL D FLIP-FLOP NATIONAL
U5	CD 4538BM DUAL MONOSTABLE MULTIVIBRATOR NATIONAL
U6	CD 4081BM QUAD 2-INPUT AND GATE BUFFERED NATIONAL

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

	Pages
1.0 Components	
1.2 Capacitors	
1.2.5 Voltage Coefficient and Temperature Coefficient Test Procedure	1.2-52 to 1.2-57

VOLTAGE COEFFICIENT AND TEMPERATURE COEFFICIENT TEST PROCEDURE

1. TEST EQUIPMENT

   A. Voltage coefficient and temperature coefficient test fixture.

   B. LF Impedance Analyzer H.P. 4192A with test leads H.P. 16048C.

   C. Regulated 0-1kVdc @10mA power supply

   D. Regulated 0-30Vdc @200mA power supply

   E. Fluke 8810A Digital Multimeter with 1000 to 1 voltage divider 80F-15

2. HOOK-UP

   A. Test fixture switches S1, S3, S4 to "OFF"

   B. Power supply power switches to "OFF"

   C. Plug in power supplies into test fixture

   D. Plug in digital multimeter with divider into test fixture. DMM power switch to "ON." Selector switch to "DC" and "AUTO."

   E. Analyzer power switch to "ON." Allow warm-up. (Capacitance and dissipation factor measurements will be made during the tests at 1kHz).

   F. Unlatch and raise up the shield.

   The following ancillary components will be connected under the shield, to their respective terminals as follows:

      1. When the "UUT's" are 0.022 uFd capacitors, R1 is a 10Mohms +/-10%, 2kV, 1W Caddock MG710 resistor and C1 is a 2.5uFd +/-10%, 2kV capacitor.

      2. When the "UUT's" are 2.2 uFd capacitors, R1 is a 0.5Mohms +/-10%, 1kV, 1W Caddock MG710 resistor and C1 is a 220uFd +/-10%, 600V capacitor.

   G. Attach R1 and C1

   H. Lower the shield and latch. (The shield must be latched to enable the interlock switch).

   I. Attach the analyzer test leads to the test fixture.

3. ALIGNMENT AND ADJUSTMENT

   A. Place 0-30Vdc power supply to "ON" and adjust the voltage to +24.0Vdc +/-1%.

B. Place test fixture "HV-ON" Switch "S1" to "ON." The "HV-ON" LED should illuminate.

C. Place 0-1kVdc power supply to "ON" and adjust the voltage to +1kVdc +/-1% (when the UUT's are 0.022uFd or to +0.5kVdc +/-1% when the UUT's are 2.2 uFd). Measurements are made with the attached DMM.

D. Place the "HV-ON" Switch S1 to "OFF." The "HV-ON" LED light should extinguish. The DMM reading should read approximately zero volts dc.

4. TEST PROCEDURE

A. Unlatch and raise the shield

B. Attach a "UUT" capacitor to the "UUT" terminals

C. Lower the shield and latch

D. Place "HV-ON" switch "SI to "ON"

E. Allow two seconds for the "UUT" capacitor to charge. (Allow two minutes for the 2.2uFd UUT).

F. Place "HI-IMP" switch "S4" to "ON"

G. Place "L-C BRIDGE OPR" switch "S3" to "ON"

H. Make "C" and "D.F." measurements with the analyzer

I. Place "L-C BRIDGE OPR" switch "S3" to "OFF"

J. Place "HI-IMP" switch "S4" to "OFF"

K. Place "HV-ON" switch "S1" to "OFF"

L. Allow two seconds for the "UUT" capacitor to discharge. (Allow two minutes for the 2.2uFd UUT).

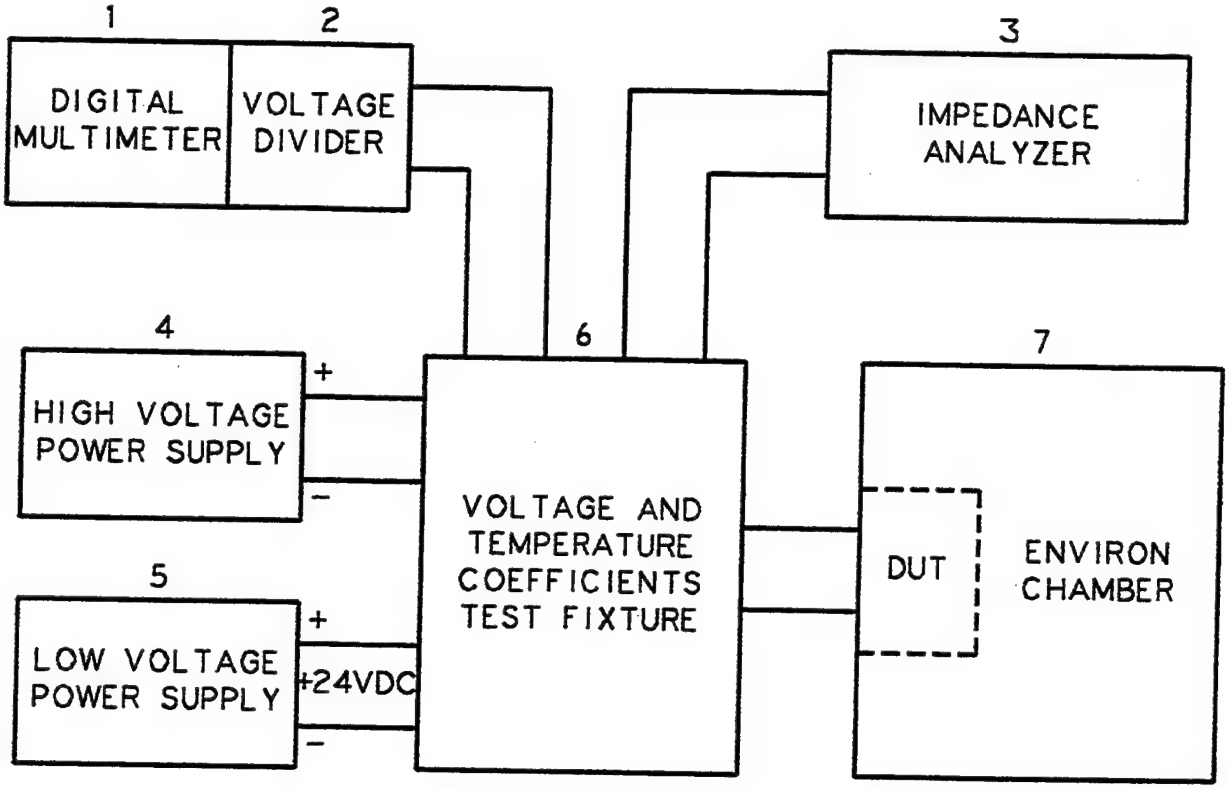
M. The DMM should read approximately zero volts dc

N. Unlatch and raise the shield

O. Replace the "UUT" capacitor with another "UUT" capacitor

P. Repeat steps "C" through "O"

Q. At the completion of the "UUT" testing place all tgest fixture switches to "OFF" and all power supply power switches to "OFF."



1. DIGITAL MULTIMETER, FLUKE 8810A (SET TO VDC).

2. 1000 TO 1 VOLTAGE DIVIDER, FLUKE 80F-15.

3. LOW FREQUENCY IMPEDANCE ANALYZER, HP 4192A WITH TEST LEADS, HP 16048C (FREQ. -1KHz).

4. REGULATED HIGH VOLTAGE POWER SUPPLY, 0 - 1KVDC @ 10 MA.

5. REGULATED LOW VOLTAGE POWER SUPPLY, 0 - 30VDC @ 200 MA.

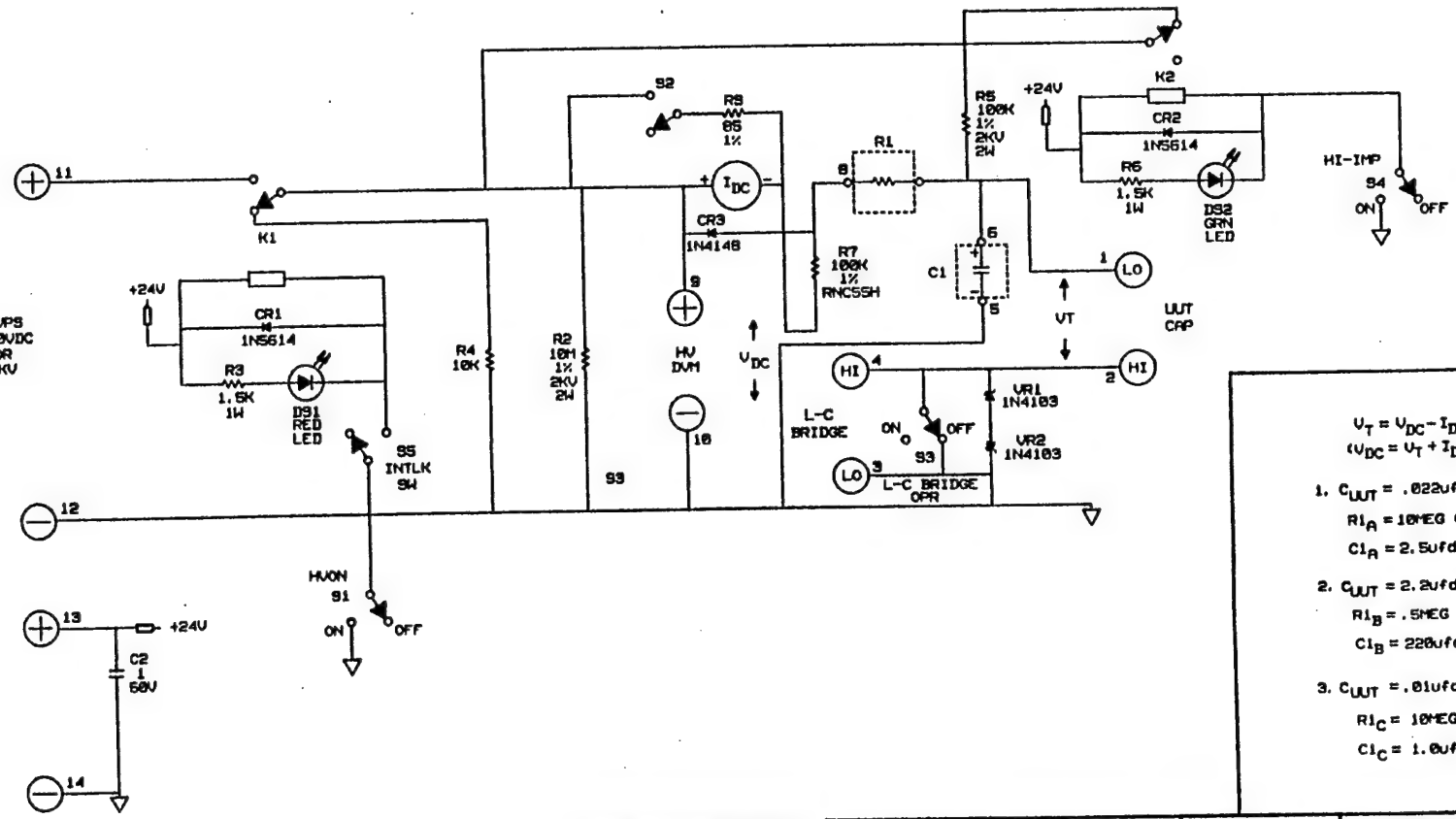
6. VOLTAGE AND TEMPERATURE COEFFICIENTS TEST FIXTURE, SEE ATTACHED SCHEMATIC AND PARTS LIST.

7. ENVIRONMENTAL CHAMBER, TENNEY (2 CUBIC FOOT).

THE DIMENSIONING AND TOLERANCING PRACTICE USED ON THIS DRAWING IS IN ACCORDANCE WITH ANSI Y14.5M-1982

/home1/kruse/CPI/SITE.INRUSH.1.5
LAST_MODIFIED=Tue Nov 21 08:16:59 1995

Notes:
1. All capacitances are uF unless otherwise indicated.
2. All resistances are Ohms. K is kilohms.
   Tolerances are 5% unless otherwise indicated.
3. Highest Ref Desgn:
   R7, R5, C2, VR2, S4, CR3, DS2, IDC, K2.



$V_T = V_{DC} - I_{DC} \cdot R1$
$(V_{DC} = V_T + I_{DC} \cdot R1)$

1. C_{UUT} = .022ufd @ $1KV_{DC}$
   $R1_A$ = 10MEG OHMS
   $C1_A$ = 2.5ufd @ 1.5KV
2. C_{UUT} = 2.2ufd @ $500V_{DC}$
   $R1_B$ = .5MEG OHMS
   $C1_B$ = 220ufd @ $500V_{DC}$
3. C_{UUT} = .01ufd @ $4KV_{DC}$
   $R1_C$ = 10MEG OHMS
   $C1_C$ = 1.0ufd @ $5KV_{DC}$

NOTICE: THIS IS A CAE DRAWING! IF MANUAL CHANGES ARE MADE, THIS DRAWING SHALL NOT BE RELEASED UNTIL THE CAE DATA-BASE HAS BEEN UPDATED.

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	XA		951121	

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED

DRAWN N. KRUSE

NORTHROP Northrop Corporation Electronics Systems Division Rolling Meadows Site Rolling Meadows, Illinois

SCHEMATIC, VOLTAGE/ TEMP COEFFICIENT TEST FIXTURE

SIZE D | CAGE CODE 26916 | SHEET 1 of 1

PARENTHETICAL DATA MARKED WITH AN ASTERISK (*) IS PECULIAR TO A PRIOR MANUFACTURER. IT DOES NOT TAKE PRECEDENCE OVER ANY OTHER DATA ON THIS DRAWING AND IS NOT CONTRACTUALLY BINDING ON EITHER THE CONTRACTOR OR THE GOVERNMENT.

VOLTAGE/TEMPERATURE COEFFICIENT TEST FIXTURE

C1C	1.0uFd +/-10%, 5KV
R5	100K +/-1%, 2KV, 2W, MG720
R1C,R1A	10M OHM +/-1%, 2KV, 1W, MG710
R1B	.5M OHM +/-1%, 1KV, 1W, MG710
C1A	2.5uFd +/-10%, 2KV
C1B	220uFd +/-10%, 600V
R2	10M OHM +/-1%, 2KV, 2W, MG720
R3,6	1500 OHM +/-5%, 1W, RCR32
C2	1.0uFd +/-10%, 50V, CKR06
VR1,2	9.1V +/-5%, 250MW, IN4103, MOTOROLA
S5	COVER/SHIELD INTERLOCK SWITCH
Ipc	100uAdc FULL SCALE (WITH SHUNT IMADC FULL SCALE)
CR1,2	IN5614
DS1,2	LED (1.2V @15MA)
K1,2	HV RELAY SPDT KILOVAC HC-3
S1,3,4	115VAC @1A SPDT
S2	115VAC @1A SPST (ISOLATED-IN CHASSIS ON METER)
R5	0-1MA READING WHEN IN CKT-IN CHASSIS ON METER), 85 OHM +/-1%
R4	10K OHM +/-5%, RCR42
R7	100K +/-1% RNC55H
CR3	IN4148

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

	Pages
1.0 Components	
1.2 Capacitors	
1.2.6 Accoustic Evaluations	1.2-58 to 1.2-76

Sonoscan INC.

Nondestructive

Acoustic Micro Imaging

Instrumentation Overview and Analytical Services Report

featuring the

Scanning Laser Acoustic Microscope (SLAM™)

and the

C-mode Scanning Acoustic Microscope (C-SAM™)

Sound Technology With Vision

530 East Green Street
Bensenville, Illinois 60106
Phone: (708) 766-7088 Fax: (708) 766-4603

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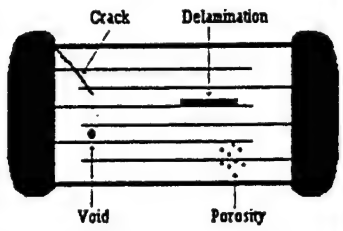
Monolithic Ceramic Capacitor Lot Qualification Program

Background

Monolithic ceramic capacitors are widely utilized in virtually all types of electronic devices. Miniaturization has been achieved through the use of specially formulated high dielectric constant materials arranged, most often, in multilayer configurations. In high reliability applications, such as space flight, defense operations and life support systems, it is essential that these components be free of physical defects like cracks, delaminations, voids and porosity.

The long term reliability of monolithic ceramic capacitors depends on their mechanical properties which cannot always be assessed by short term or accelerated electrical life tests. Internal cracks and delaminations which are not detected by electrical tests may propagate when subjected to environmental stresses and thermal cycling. During the life of the component, these defects may reach a critical size, causing catastrophic device or system failure. Additionally, large voids and excessive porosity may decrease the effective dielectric strength of a component, and under the continual influence of an electrical field, its overall electrical characteristics may be compromised.

TYPICAL CAPACITOR DEFECTS



Lot Qualification Program Advantages

- *Guarantees reliability*
- *Routine lot sampling for high volume users*
- *Identifies defective lots prior to use or assembly*
- *Integrates with vendor qualification*
- *Integrates with incoming inspection*
- *100% inspection of high reliability components*
- *Develop accept/reject criteria*
- *Integrate with SPC/AQL or end user criteria*
- *Reduces rework costs*
- *Online feedback to manufacturing and procurement*

Because physical anomalies can jeopardize a capacitor's reliability, a method must be utilized for accurately determining the presence of such defects. However, inherent problems exist with such traditional test methods as DPA (destructive physical analysis). In addition to being time consuming, costly and geared toward small sampling sizes, submicron laminar defects will often go undetected. This can be detrimental as it may lead to acceptance of a lot which should have been rejected. In some cases, DPA procedures may actually induce flaws, which can mislead the analysis and result in unwarranted rejection of acceptable components.

Acoustic Microscopy is a recognized technique for nondestructively examining monolithic ceramic capacitors. Acoustic Microscopy also reveals internal physical defects which cannot be detected visually, by X-ray or by conventional C-scanning methods. Both SLAM™ and C-SAM™ techniques provide valuable insight regarding the internal features of each component. Capacitors ranging from the smallest (mm size) multilayer chips to the largest (cm size) high voltage, leaded, discoidal and encapsulated types, are amenable to Acoustic Micro Imaging nondestructive screening.

Sonoscan, Inc. 530 East Green Street Bensenville, Illinois 60106
Telephone: (708) 766-7088 Fax: (708) 766-4603

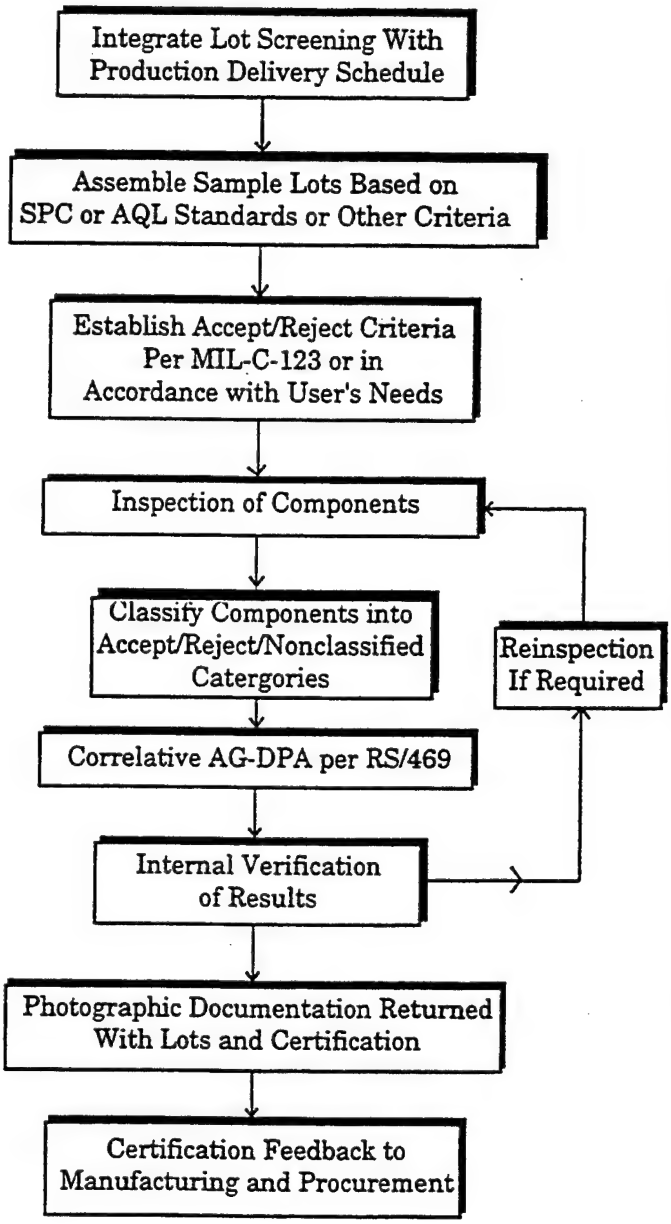
Lot Qualification Program Description

The Monolithic Ceramic Capacitor Lot Qualification Program (MCCLQP) has been developed to integrate routine capacitor screening with the most stringent production schedules. Sample lots are assembled and submitted for evaluation based on individual customer requirements, typically in accordance with Statistical Process Control (SPC), Acceptance Quality Level (AQL) standards, or 100% high reliability screening.

At the start of each customer project, each component is nondestructively examined for internal defects. The components are segregated into categories identified by the type of defects found, such as cracks, delaminations, voids, porosity, shifted electrodes, inadequate end margins, knit line defects and other anomalous characteristics. These categories are each classified as acceptable, rejectable or nonclassified based upon the criteria imposed by the customer, the end user of the product, or by specific military specifications. After segregation, representative acoustic images and corresponding acoustically guided destructive physical analysis (AG-DPA) are obtained for each lot tested.

The next important phase of each project involves the validation of the categories and the corresponding data. This phase is performed by an independent analyst to insure that objectivity is maintained. This is an insurance step to guarantee, with the highest confidence factor, that the customer is receiving the highest quality data.

Lot Qualification Procedural Flow Chart



Upon completion of the project, the customer receives certification of the results along with supporting data and interpretation. This report provides information outlining the quality of the lot which can be relayed to manufacturing. This information can also be useful in procurement and contract negotiations with your chosen vendor.

Lot Qualification Program in Action

In many organizations, capacitor certification is performed on an annual basis where qualification is really applied to the vendor's "evaluation" parts rather than lot by lot inspection. As pointed out in the following excerpts, routine incoming inspection and lot qualification have distinct advantages.

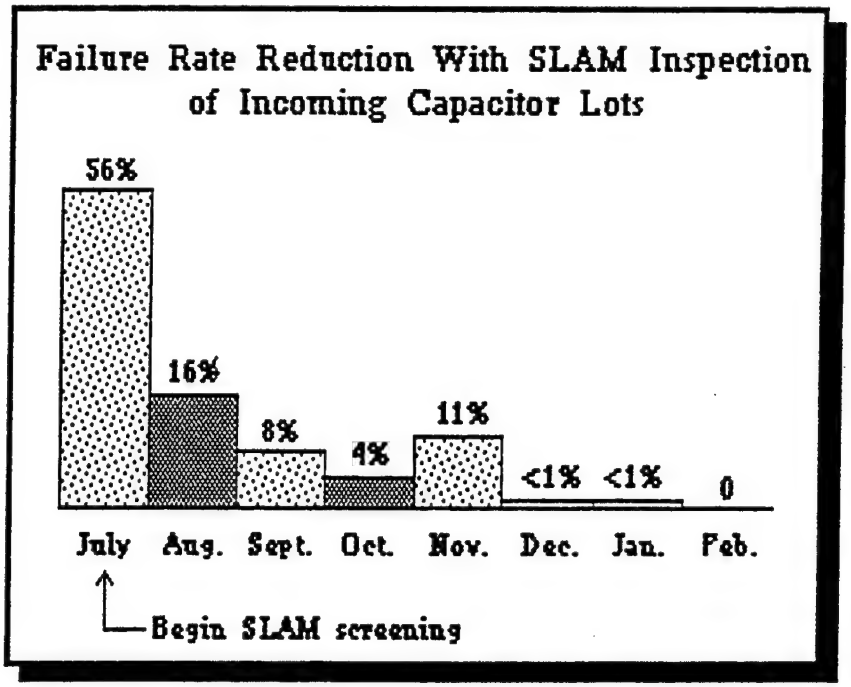
"...we depended upon cross sectioning to determine the failure mechanism and root cause of a chip capacitor failure. The problem was that cross sectioning by itself is highly operator / technique dependent. . . .

To section into a device without knowing what you are looking for is very difficult since it is possible to polish away the defect site in sectioning or miss very subtle defects during optical inspection. . . .

SLAM allows us to inspect a device for any discontinuities (i.e., defects) in the ceramic material. This lets us examine a device to locate any defects in the ceramic material prior to sectioning so that we know where to look, taking the guesswork out of analyzing a failure.

. . . We first instituted SLAM as a failure analysis tool to examine the in-process fallout we were experiencing.

. . . By doing this we were able to identify the steps in our process that were most damaging to chip caps and needed the tightest controls. These controls have virtually eliminated process-induced line fallout.



The second application we use SLAM for is to inspect for vendor-induced defects. . . .

Reject information was fed back to the suppliers so that they could enact the necessary corrective actions. Catching defective devices before being assembled into product has yielded low in-process fallout levels and significant savings in dollars and aggravation. . . .

Today we audit inspect lots to ensure device quality as part of incoming inspection requirements. . . .

The results of how using SLAM improved the reliability of incoming lots of capacitors are depicted in the graph above.

. . . The third application of SLAM is as a qualification tool. The SLAM allows us to inspect all chip capacitors submitted for qualification testing prior to electrical testing. . . .

Since a typical qualification electrical test can take several weeks to prepare and perform, SLAM inspection can save a great deal of time and money by identifying potential problems before they occur. . . .

This prevents us from wasting a great deal of time and resources on parts that we would eventually fail. SLAM prior to qualification is essentially a bigger magnifying lens to use to scrutinize a new vendor. . . . its primary function for our laboratory is for qualification, screening, and failure analysis of ceramic devices."

Excerpts from Surface Mount Technology, Vol. 3 No. 5, September 1989, pp. 39-43.

Sonoscan INC.

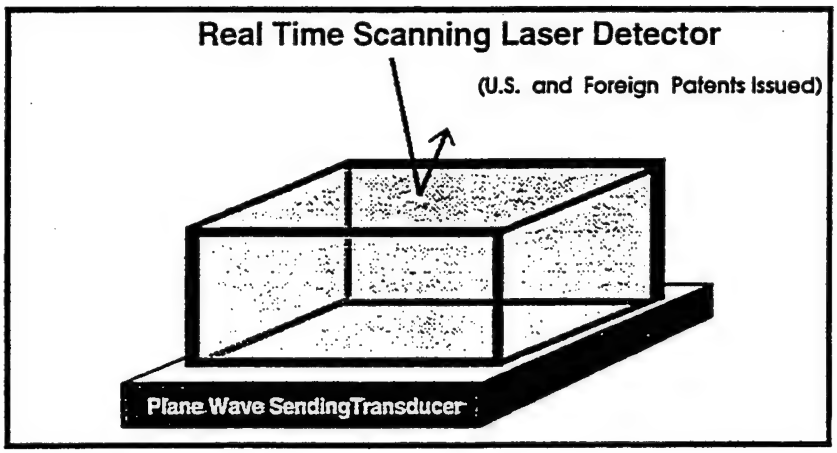
SLAM

Principles of Operation

In SLAM imaging, a collimated beam of continuous wave ultrasound is produced by a piezoelectric transducer located beneath the sample. Since ultrasound will not travel through air, a fluid couplant such as deionized water is selected. After entering the sample, the ultrasonic wave is affected by the homogeneity of the material. Wherever there are anomalies the ultrasound is differentially attenuated and the resulting image appears dark. Areas within the sample that are well bonded and uniform transmit the ultrasound and appear bright.

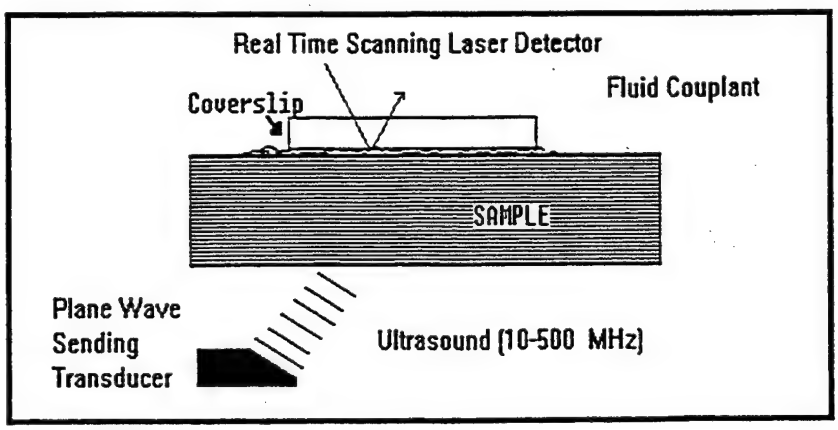
For most samples (which do not have a shiny, optically reflective surface) a mirrored plastic block or coverslip is placed in close proximity to the sample and acoustically coupled. The laser is focused to a small spot on the mirror and is reflected back to a photodetector where the signal is processed. The image is then displayed on a high resolution video monitor. The simplest geometries for acoustic imaging are flat, however, with proper fixturing, complex shapes can also be accommodated.

SLAM images can also be quantitatively analyzed. Portions of the image can be scanned to produce attenuation profiles which relate to material properties. Remember, in SLAM, samples with good transmission appear bright and those with poor transmission (highly attenuated) appear dark; between are various levels of grey. Analysis of a feature is often a case of knowing how much a suspected anomaly attenuates the ultrasound compared to the background.



The Sonometer™ is the analytical portion of this tool that makes measurements of attenuation over specific areas of a sample. Sonometer™ can be used to document the extent of defects by virtue of their localized contribution to signal levels. It can be used to obtain information about background texture, porosity, grain size, etc., and it can standardize the data relative to other samples or other areas within a sample that are deemed of interest.

In operation, the Sonometer™ is used to define a "data window" on the acoustic image CRT. The size and position are selected by the operator. At one edge of the CRT are two variable height bar graphs which display the signal level indicated. When the data window is positioned over a disbond the bar graph reads out a lower signal level relative to the reference. By using a precision attenuator, the signal levels shown by the bar graphs are made equal and the attenuation data is recorded. By varying the window size, tiny inhomogeneities or average readings over the entire sample can be calculated.



C-SAM

Principles of Operation

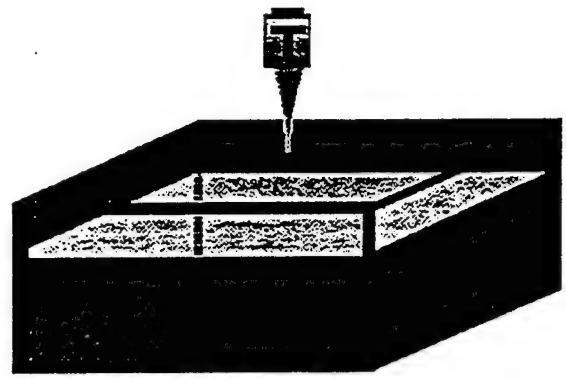
The C-Mode Scanning Acoustic Microscope is a pulse-echo (reflection type) microscope that generates images by mechanically scanning a transducer in a raster pattern over the sample. A focused spot of ultrasound is generated by an acoustic lens assembly at frequencies typically ranging from 10-150 MHz. The ultrasound is brought to the sample by a coupling medium, usually deionized water or an inert fluid. The transducer alternately acts as sender and receiver, being electronically switched between the transmit and receive modes.

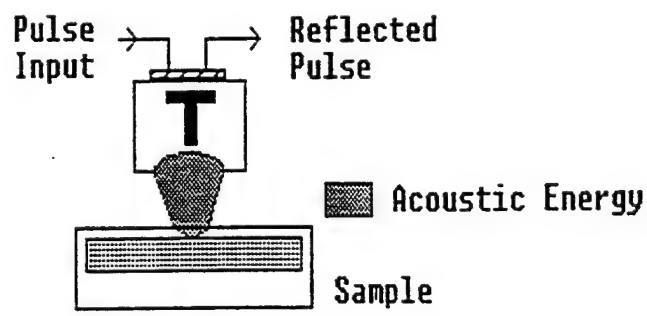
A very short acoustic pulse enters the sample and return echoes are produced at specific interfaces within the part. The return times are a function of the distance from the interface to the transducer. An oscilloscope display of the echo pattern, known as the A-Scan, clearly shows these levels and their time/distance relationships. This provides a basis for investigating anomalies at specific levels within a part. *For wave form and color map interpretation see additional text.*

An electronic gate is positioned in time and controlled to open for a defined duration allowing only the information from a specific level to be imaged while excluding all other echoes. The "gated" echo modulates a CRT which is synchronized with the transducer's position. In this way images are produced in raster fashion on the CRT. Complete images are produced in about 10 seconds.

In C-SAM images the contrast changes compared to the background constitute the important information. Voids, cracks, disbonds and delaminations provide high contrast and are easily distinguished from the background. Combined with the ability to "gate" and "focus" at specific levels C-SAM is a powerful tool for analyzing the nature of any defect within a sample.

Very High Speed Transducer Actuator
(U.S. and Foreign patents Issued)





Sonoscan INC.

Ceramic Capacitor
Screening Procedure
752B
Revision 5.95

Capacitors submitted for analysis are evaluated according to our internal Procedure 752B, Revision 5.95, unless otherwise directed by the customer. This procedure is as follows:

Procedural Steps:

I. Incoming capacitors are given an identification number. If multiple lots are submitted, each lot is separately identified.

II. Components are counted and inspected for visible surface defects such as cracks and chip outs.

III. Components are nondestructively inspected on SLAM or C-SAM for internal flaws such as cracks, delaminations, voids, porosity and shifted electrodes.

IV. After screening, components are divided into specific categories depending on their acoustic signature. If, after screening 10% of the lot, the preliminary categorization contains less than a 90% yield (10% fallout) the screening will be halted and the customer will be notified immediately. Upon notification a decision will be made as to continue screening, submit additional samples or stop screening entirely.

V. To insure the highest quality data, a random sample of 10% of the "Accepted" components from each lot are rescreened by a second Applications Engineer; *(minimum 10 units, maximum 100 units).*

This does not apply to lots which have undergone validation using both SLAM and C-SAM imaging techniques. Nor does it apply to lots with less than 50 components.

VI. When necessary or contracted, Acoustically Guided-Destructive Physical Analysis (AG-DPA) cross sections are performed based on the procedures in ANSI/EIA-RS-469-B. The acoustic micrograph is then correlated with the cross section optical micrograph. These results are also compared with our previous experience for similar capacitors. Accept/reject criteria and component categorization is consistent with the guidelines set forth in this document.

In some cases, Q-BAM™ may be substituted for Acoustically Guided Destructive Physical Analysis (AG-DPA).

VII. Example acoustic micrographs are generated showing the severity of the anomalies. These micrographs are delivered in report form and provide a "roadmap" for defect isolation, evaluation and quantification.

VIII. Capacitor categories are tallied, labeled as "Accepted", "Nonclassified" or "Rejected", repackaged and returned according to stated shipping instructions. Certification documents summarizing the outcome of the analysis are included in the final inspection report.

Category Description:

"Accepted" Indicates that the components in this category are the best in the lot and are free of internal defects. Comments relating to this category alert the end user to additional anomalous characteristics based on our findings and past experience.

"Rejected" Indicates that internal flaws have been detected including cracks, delaminations, voids, shifted electrodes and/or porosity. These parts are considered to be mechanically flawed and pose a reliability risk. These components are not recommended for use.

"Nonclassified" Pertains to components with certain types of anomalies. These typically require further investigation in order to qualify the anomalous condition and its significance as it relates to component performance in the intended application. These include components containing small voids, porosity and pre-chip outs.

Reference documents:

MIL-C-123B, Appendix C:
Capacitors, fixed, ceramic dielectric, high reliability general specification. August 6, 1990.

ANSI/EIA-RS-469-B:
Standard test method for destructive physical analysis of high reliability ceramic monolithic capacitors. August 1988.

MIL-STD-105E:
Sampling procedures and tables for inspection by attributes. April 1963.

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Summary

If a ceramic capacitor fails, the cost of rework is usually orders of magnitude more costly than the faulty component. The impact, if this capacitor is discovered as a result of a field failure, can be catastrophic. This failure is not only expensive to repair, but also potentially injurious to the company's reputation for quality.

In order to avoid such a catastrophe, the reliability of capacitors prior to assembly must be insured. The Monolithic Ceramic Capacitor Lot Qualification Program (MCCLQP) makes it easy to do this by eliminating defective components prior to use.

This progam adjusts easily to the requirements of the end user, as the lot accept/reject criteria are developed in consideration of the intended application. For example, it has been shown that capacitors used in surface mount applications must endure additional stresses caused by pick and place equipment and accelerated temperatures of reflow ovens. Here, the mechanical integrity of a component is critical to the reliability of the product. In cases, adherence to a strict lot qualification acceptance criterion is recommended. At other times, the acceptance criterion can be relaxed.

SLAM™ produces images in real time making screening attractive for high volume inspection and rapid turnaround of data while C-SAM™ offers level specific and crossectional views geared more toward indepth analysis. "MCCLQP" integrates easily with "dock to shop" production schedules and can be tailored for routine lot screening or 100% inspection required for Class S and other high reliability components.

The expertise of Sonoscan Laboratories and the uniqueness of SLAM™ and C-SAM™ screening make the Lot Qualification Program an important aspect of standard incoming inspection. This program helps determine the reliability and quality of passive components prior to usage and assembly. By making "Lot Qualification" a routine portion of your incoming inspection, you will be able to consistently monitor capacitor quality which directly affects product reliability and customer satisfaction.

A Final Note About Sonoscan...

Since our incorporation in 1973, Sonoscan has been exclusively dedicated to the pursuit and development of Acoustic Microscopy Technologies. Providing both government and industry with instrumentation and services, we continue to remain a leader in the advancement of this field. As a result of our advances and dedication, Sonoscan received the prestigious "IR 100" award in 1975 for the development of SLAM, TRW's "Supplier of the Year" award in 1985 for developing a custom Scanning Acoustic Microscope, and in 1990, Sonoscan received the U.S. Small Business Administrator's Award for Excellence in recognition of outstanding contributions to the U.S. Air Force.

Our technologies have been issued patents, and our innovative research and development efforts have led the way to numerous contracts by various industry and government organizations, such as DoE, NSF, DoD and SBIR. To date, Sonoscan personnel have authored over 100 technical papers, contributed to the creation of industry and military standards and served as organizers and chairpersons of technical symposiums and workshops.

Our involvement in the ceramic capacitor market dates back to the initiation of the first CARTS (Capacitor and Resistor Technology Symposium) in 1981. We have worked jointly with private and public entities to enhance the usability and reliability of the components and assemblies used in today's manufacturing. We are engaged in virtually all aspects of the contract testing, development, manufacture and sale of high resolution, ultrasonic imaging equipment for the nondestructive inspection of advanced materials and microelectronic components. Our systems are widespread in the United States and in 14 other nations, and the services of our Laboratories have been used by thousands of companies. We are excited that you have chosen Sonoscan and Acoustic Microscopy Technologies to address your current NDT needs, and it is our commitment to provide you with the response, dedication and attention you deserve.

\caprpts\lastpg.pm4

INSPECTION REPORT
MONOLITHIC CERAMIC CAPACITORS

Date: _____
Item Number: _____

Components Submitted By:

_____
_____
_____
_____
_____

Attn: _____
Phone: _____

P.O. Number: _____
Internal Control Number: _____

Manufacturer: _____
Part Number: _____
Lot / Date Code: _____
Quantity: _____
Capacitance: _____
Voltage Rating: _____
Overall Size: _____
Dielectric Type: _____
Configuration:

- ☐ Bare Chip
- ☐ Terminated
- ☐ Leaded
- ☐ Discoidal
- ☐ High Voltage
- ☐ Encapsulated

Other: _____

Results and Summary

Accepted:		_____
Defect Free	_____	
Shifted Electrodes	_____	
Surface Imperfections	_____	
Other	_____	
Rejected:		_____
Delaminations	_____	
Porosity	_____	
Voids	_____	
Cracks	_____	
Shifted Electrodes	_____	
Other	_____	
Nonclassified:		_____
Voids	_____	
Porosity	_____	
Pre-Chip Outs	_____	
Other	_____	
Retained by Sonoscan, Inc.		_____
Total Parts Returned		_____

Inspection Equipment

System Serial Number: _____
Transducer Serial Number: _____
Frequency: _____
Insonification Angle: _____
Field of View: _____
Other: _____

Comments: _____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Certification

_____
Inspector's Signature

_____
Validator's Signature

Inspection Hotline: 1-800-950-2NDT

Sonoscan INC.

COMPANY _____

CONTACT _____

PROJECT # _____ DATE _____

CAPACITOR ACOUSTIC MICROGRAPH

COMMENTS:

_____

_____

_____

_____

_____

_____

_____

_____

_____

SYSTEM SPECIFICATIONS

- ☐ 2330
- ☐ 2140
- ☐ SLAM
- ☐ 300DX
- ☐ 3100
- ☐ C-SAM

FREQUENCY/FOV (mm)

☐ 10 MHz	35 x 26
☐ 24 MHz	14 x 10.5
☐ 30 MHz	14 x 10.5
☐ 100 MHz	3.5 x 2.6
☐ ___ MHz	_____

ANALYST:

SAMPLE IDENTIFICATION

ITEM # _____

PART # _____

LOT # _____

GROUP # _____

SAMPLE CLASSIFICATION

Defect Free

Porosity

Surface Imperfection

Surface Chip Out

Pre-Chip Out

Shifted Electrodes

Void

Internal Delamination

Encapsulant Delamination

Termination Delamination

Crack

Other _____

Sonoscan INC.

Acoustically Guided
Destructive Physical Analysis

Customer:_____

_____

_____

_____

Project No.:_____

Date:_____

Item No.:_____

Part No.:_____

Lot No.:_____

Lot Classification:

_____

Magnification:_____

Comments:_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Number of Electrodes:_____

Dielectric Thickness:_____

Cover plate 1:_____

Cover plate 2:_____

Capacitor Thickness:_____

Capacitor Width:_____

Inspection Hotline: 1-800-950-2NDT

Sonoscan INC.

Acoustically Guided
Destructive Physical Analysis

Customer:_____

Project No.:_____

Date:_____

Item No.:_____

Part No.:_____

Lot No.:_____

Lot Classification:

Magnification:_____

Comments:_____

Inspection Hotline: 1-800-950-2NDT

Sonoscan Inc.

NON CONFORMING MATERIAL NOTIFICATION

Date: _____

Attention: _____
Phone: _____
Fax: _____

Components Submitted By:

_____
_____
_____
_____
_____

P.O. Number: _____
Internal Control Number: _____

Manufacturer: _____
Part Number: _____
Lot / Date Code: _____
Quantity: _____

Configuration:

- ☐ Bare Chip
- ☐ Terminated
- ☐ Leaded
- ☐ Discoidal
- ☐ High Voltage
- ☐ Encapsulated

Other: _____

PRELIMINARY

Total Lot Quantity _____

Quantity Screened _____
Quantity "Accepted" _____
Quantity "Rejected" _____
Quantity "Nonclassified" _____

We have detected nonconforming material equal to or greater than 10% and are informing you of this status based on Sonoscan's internal screening procedure, 752B Revision 5.95.

_____
Inspector

_____
Inspector's Signature

Please inform us as to the following:

☐ Continue Screening
Comments: _____
_____
_____
_____

☐ Additional Parts Will Be Forwarded:
Estimated arrival: _____
Comments: _____
_____
_____
_____

☐ Halt Screening Entirely:
Comments: _____
_____
_____
_____

Please acknowledge receipt of this correspondence.

_____
Customer's Signature

530 East Green Street, Bensenville, IL 60106 USA
Telephone: (708) 766-7088
Fax: 011-1 (708) 766-4603
Telex: 754278
1.2-71

COMPONENT SUBMISSION FORM

MONOLITHIC CERAMIC CAPACITOR LOT QUALIFICATION PROGRAM

To expedite delivery, FAX this form in advance to Sonoscan, Inc. at (708) 766-4603, or submit this form with your next shipment of capacitors to:
Sonoscan, Inc., Mail Stop: LQP, 530 East Green Street, Bensenville, IL 60106

COMPONENTS SUBMITTED BY:
CUSTOMER NAME: _____
COMPANY: _____
ADDRESS: _____
CITY, STATE: _____
PHONE: _____ ZIP: _____

DATE: _____
P.O. #: _____
PROJECT #: _____
FOR QUESTIONS CONTACT:
_____
PHONE: _____

DELIVER TESTED COMPONENTS TO:
CUSTOMER NAME: _____
COMPANY: _____
ADDRESS: _____
CITY, STATE: _____
PHONE: _____ ZIP: _____

RETURN SHIPPING ROUTE:
UPS: ☐ Red ☐ Blue
FEDERAL EXPRESS: ☐ Standard ☐ Priority
☐ PREPAID* ☐ COLLECT
ACCOUNT #: _____
*Unless otherwise specified, all prepaid accounts will be shipped via Federal Express (Priority 1) and invoiced for incurred charges.

PRODUCT INVENTORY

ITEM 1:
MANUFACTURER: _____
PART #: _____
CAPACITANCE: _____
VOLTAGE RATING: _____
LOT/DATE CODE: _____
QUANTITY SUBMITTED: _____
QUANTITY TO TEST: _____

ITEM 2:
MANUFACTURER: _____
PART #: _____
CAPACITANCE: _____
VOLTAGE RATING: _____
LOT/DATE CODE: _____
QUANTITY SUBMITTED: _____
QUANTITY TO TEST: _____

For additional lots, please photocopy this page.

INSPECT PER:
☐ MIL-C-123
☐ AQL Standards
☐ Other _____

AUTHORIZED BY: _____
PLEASE PRINT: _____

SPECIAL HANDLING INSTRUCTIONS:
_____
_____

COMMENTS: _____
_____
_____

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Capacitor Bibliography

STANDARDS:

ANSI/EIA STANDARD 469-B: "Standard Test Method for Destructive Physical Analysis of High Reliability Ceramic Monolithic Capacitors", December 1988.

GOVERNMENT-INDUSTRY DATA EXCHANGE PROGRAM: "Evaluation of Non-Destructive Techniques to Detect Flaws in Multi-Layer Ceramic Capacitors", Report #E324-0270, May 27, 1981.

MILITARY STANDARD MIL-C-55681B: "Capacitors, Chip, Multiple Layers, Fixed, Unencapsulated, Ceramic Dielectric, Established Reliability, General Specification For", April 5, 1985.

MILITARY SPECIFICATION MIL-C-123A: "Capacitors, Fixed, Ceramic Dielectric, (Temperature Stable and General Purpose), High Reliability, General Specification For", March 13, 1981.

MILITARY SPECIFICATION MIL-F-28861: "Filters and Capacitors, Radio Frequency/Electromagnetic Interference Suppression, General Specification For", August 20, 1983.

MILITARY STANDARD MIL-STD-105D: "Sampling Procedures and Tables for Inspection by Attributes", May 10, 1989.

NATIONAL MATERIALS ADVISORY BOARD AND NATIONAL ACADEMY OF SCIENCES: "The Reliability of Multilayer Ceramic Capacitors", Report #NMAB-400, 1983.

REFERENCES:

Bloomer, C., Mepham, R. and Sonnicksen, M., "Advanced Failure Analysis Techniques for Multilayer Ceramic Chip Capacitors", International Symposium for Testing and Failure Analysis (ISTFA), November 1987, pp. 25-33.

Bloomer, C., Mepham, R. and Sonnicksen, R.M., "Scanning Laser Acoustic Microscopy (SLAM)." Proceedings, Reliability: Key to Industrial Sucess, ASM International, 1987, pp. 157-164, (SLAM).

Bowers, J.S., Stopher, J., "A Review of the Use of ACCIV vs. DC Life to Determine the Reliability of High Voltage Capacitors", 13th Capacitor and Resistor Technology Symposium (CARTS), March 1993, pp. 107-115.

Canner, J., "Non-Destructive Testing of MLC Using Two Types of Ultrasonic Microscopes", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), March 1991, pp. 54-61.

Commare, D., "Multilayer Ceramic Capacitors", Hybrid Circuit Technology, December 1991.

Commare, D., "Nondestructive Evaluation of MLCCs", Ceramic Industry, June 1993, pp.38-41.

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Capacitor Bibliography

Kessler, F.A., "Defect Detection in Electronic Components Using Real-Time Acoustic Microscopy", Materials Evaluation, May 1986, pp. 44.

Kessler, L.W., Ewell, G.J. and Semmens, J.E., "High Frequency Ultrasonic Attenuation of Ceramic Capacitors as an Indicator of Quality", Proceedings of the 36th Annual Electronic Components Conference, May 1986.

Kessler, L.W., and Semmens, J.E., "High Frequency Ultrasonic Visualization and Characterization of Multilayer Ceramic Capacitors by Means of SLAM", Proceedings, Symposium on MLC Reliability, Pennsylvania State University, University Park, PA May 11-12, 1989.

Kessler, L.W., Ewell, G.J. and Semmens, J.E., "Use of the SLAM as a Tool for Ceramic Capacitor Process Development and Optimization", Preceedings from the Capacitor and Resistor Technology Symposium (CARTS), March 1986, pp. 32-41.

Kessler, L.W., and Semmens, J.E., "Characterization of the Microstructure of Ceramics Used in Multilayer Ceramic Capacitors by Means of Scanning Laser Acoustic Microscope", American Ceramics Society, Vol. 72, No. 12, December 1989.

Kessler, L.W., and Semmens, J.E., "High Frequency Ultrasonic Visualization and Characterization of Multilayer Ceramic Capacitors by Means of Scanning Laser Acoustic Microscopy (SLAM)", Proceedings of MLC Reliability Symposium, Pennsylvania State University, May 1989.

Kessler, L.W. and Semmens, J.E., "Nondestructive SLAM Analysis of Ceramic Capacitors: An Overview of Experiences From 1980 - 1989", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), March 1989, pp. 63-73.

Kessler, L.W., Semmens, J.E. and Ewell, G.J., "Low Voltage IR Failures in Ceramic Capacitors: Screening by SLAM and Methanol Immersion", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), March, 1985, pp. 169-190.

Kessler, L.W., Semmens, J.E., and Ramirez, P., "Nondestructive SLAM Analysis of Ceramic Capacitors: An Overview of Experiences from 1980-1987, Proceedings from the First European Capacitor and Resistor Technology Symposium, October 1987, pp. 91-104.

Leppanen, M. "Use and Misuse of Destructive Physical Analysis", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), April 1982, pp. G1-1 to G1-6.

Moore, D.E. "Statistical Process Control (SPC) and Parts Per Million (PPM) Quality Techniques for Military Specifications on Passive Electronic Components", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), March 1989, pp. 139-142.

Santangelo, L. and Kessler, L.W., "Acoustic Microscopy: A Key Inspection Tool for Improving the Reliability of Surface Mount Capacitors and Plastic IC Packages", Surface Mount Technology, September 1989.

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Capacitor Bibliography

Semmens, J.E., Kessler, L.W. and Ewell, G.J., "Nondestructive Inspection of Ceramic Capacitors: Detection of Apparent Flaw Growth in Parts Submitted to Low-Voltage Humidity Exposure", International Symposium for Testing And Failure Analysis (ISTFA), November 1985.

Speece D., Ewell G., Siplon J., "Surge Current Testing of Ceremic Capacitors," 14th Capacitor and Resistor Technology Symposium (CARTS), March 1994, pp.64-69.

Suarez, R.M. , "Experiences in the Development of High Capacity MLC Stacks", 13th Capacitor and Resistor Technology Symposium (CARTS), March 1993, pp.45-50.

Vorres, C.L., "Nondestructive Testing Using Acoustic Microscopy and Correlative Analysis", NMAB Workshop on Reliability of Nultilayer Ceramic Capacitors, Washington, D.C., March, 1982.

Vorres, C.L., Yuhas, D.E. and Kessler, L.W. "Nondestructive Evaluation of Ceramic Chip Capacitors by Means of the Scanning Laser Acoustic Microscopy", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), April 1982, pp. F3-1 to F3-6.

Vorres, C.L., Yuhas, D.E., and Semmens, J.E., "Acoustic Visualization of Stressed Ceramic Capacitors", International Symposium for Testing and Failure Analysis (ISTFA), 1982, pp. 215-218.

Vorres, C.L., Yuhas, D.E., and Semmens, J.E., "Re-ecaluation of Ceramic Capacitors with the Scanning Laser Acoustic Microscope Following Life Test", Proceedings from the Capacitor and Resistor Technology Symposium (CARTS), March 1983.

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DESIGN AND MANUFACTURING GUIDELINES FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

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1.3 Transformers	
1.3.1 Test Vehicle Age Testing	1.3-1 to 1.3-8

Test Procedure for MANTECH Program
Prototype Transformers Aging Characteristics

1.0 SCOPE

This document defines the test requirements and procedures for high voltage transformers as described in paragraph 3.2.

2.0 PURPOSE

The purpose of this test is to investigate aging characteristics of high voltage transformers under conditions of electrical and environmental stress screening as required by the MANTECH program.

3.0 DOCUMENTS

Use the latest issue of drawings and specifications in effect or as specified herein.

3.1 TEST STANDARDS

ASTM-D-1868	Standard Method for Detection and Measurement of Partial Discharge Pulses
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-389	Recommended Practice for Testing Electronic Transformers and Inductors
MIL-STD-45662	Calibration System Requirements

3.2 Northrop ESD Drawings

050-005194	Transformer, Power Step-up
159-000676	Transformer, Power Step-up (Manufacturing Drawing)

3.3 Applicable Documents

MIL-T-27	General Specification for Transformers and Inductors

4.0 TEST EQUIPMENT

Substitute equipment may be used provided such is of equal or greater accuracy. Test equipment calibration shall comply with the requirements of MIL-STD-45662.

Precision Inductance Analyzer
Wayne Kerr, Inc.
Model No. 3245
Serial No. 431
Calibration: 6 months

Pulse Height Analyzer
Traco Northern
Model No. TN-1705
Serial No. B110513
Calibration: 6 months

Environmental Chamber
Blue M
Model No. 1004-3BMP
Serial No. Rc4-111
Calibration: 6 months

High Voltage DC Power Supply
Hipotronics
Model No. 850B/10120
Serial No. 014416-00
Calibration: 6 months

Corona Detection System
Biddle
Model No. 663006-01
Serial No. 1169
Calibration: 1 year

AC High Voltage Power Supply
Hipotronics
Model No. 730-2CI
Serial No. 012904-00
Calibration: 6 months

Digital Multimeter
Fluke
Model No. 8600A
Serial No. 2768075
Calibration: 6 months

5.0 TEST SAMPLE

5.1 Sample and Sample Group

A test sample shall consist of a transformer per paragraph 3.2, drawing 050-005794. A sample group shall consist of a number of test samples which receive the same environmental thermal cycling procedure.

5.2 Sample Preparation

The test samples shall be fabricated per paragraph 3.2, drawing 159-000676.

5.3 Sample Acceptance Test

The test samples shall be tested as specified in the acceptance tests given in drawing 050-005794.

5.4 Sample Inspection

The transformers shall be inspected visually and mechanically for conformance to the requirements of paragraph 3.2, drawing 050-005794.

5.5 Corona Testing

Corona testing shall be conducted per the Northrop ESD MANTECH Corona Measurement Procedure.

6.0 TEST PROCEDURES

6.1 Data Recording

Information on the Transformer Configuration will be recorded per Table 1 at the time of initial build of each transformer. Data from corona testing and periodic transformer testing will be recorded every 100 thermal cycles per Table 2.

6.2 Partial Discharge (Corona)

All partial discharge measurements will conform to the procedures of ASTM-D-1868-81 (1986) - Standard Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.

All measurements will employ the basic circuit of ASTM-D-1868 (1986), Figure 1, Circuit No. 1.

These measurements will utilize the Biddle Partial Discharge System presently installed at the Northrop ESD - Rolling Meadows Facility.

The two high-voltage windings will be connected in series for the corona test. Measurements will be made from the transformer secondaries to ground. For the purposes of this test, ground will consist of the transformer shield, primary winding and core.

Corona inception voltage (CIV) and corona extinction voltage (CEV) will be measured and recorded using a 60Hz source. The source voltage will not exceed 10KV rms for this test. If the CIV cannot be determined within these limits, the CIV will not be determined. The corona profile (number of counts versus pico-coulombs [pC]) will be determined using a one minute test. The range will be from 20pC to 200pC with channel discriminations of 0.4pC. The profiles will be saved on a computer media. The test timing and data collection will be controlled by the Nuclear Data Pulse Height Analyzer. The set-up procedure will be per the previously written "MANTECH Corona Test Procedure".

6.3 THERMAL CYCLE

Transformers will be subjected to 3000 hours of the following temperature profile. High-voltage is applied to the secondary windings continuously. The applied high voltage for the entire test group will be the calculated voltage required to induce a maximum peak stress of 200 volts per mil in the transformer's insulation system. External power will be applied to the transformers (using the circuitry in Figure 1) as described in Step 2 below.

Step 1: Bring the transformer internal temperature to -55 +0/-5 degrees C and soak for 2 hours. The time to reach thermal equilibrium at -55 degrees C in the test transformers is approximately 1 hour; however, this is to be experimentally verified.

Step 2: Bring the transformer internal temperature to +100 +/-5 degrees C and soak for 2 hours. The time to reach thermal equilibrium at +100 degrees C is approximately 1 hour; however, this is to be experimentally verified. During the last hour of the soak, the transformer primaries shall be powered with a 40kHz source to provide internal transformer heating in the primary and the shorted secondary windings. The following internal hot-spot temperatures will be achieved:

Group 1 (6 transformers): 120 +/-5 degrees C
Group 2 (12 transformers): 150 +/-5 degrees C
Group 3 (6 transformers): 170 +/-5 degrees C

Temperature monitoring will be executed with thermocoupled transformers associated with each group. The thermocoupled transformers shall not have high voltage applied for simplicity of the testing procedure.

After the completion of each 100 temperature cycles, the transformers under test will be removed from the temperature chamber and the transformer characterization tests and corona tests will be repeated on each unit. Temperature cycling will resume when test data has been recorded.

Should a transformer fail during the thermal cycling procedure, the failed unit will be removed from the test fixture and cycling resumed with the remaining units. Time of failure will be recorded and the failed unit will be examined to determine the cause of failure.

The temperature cycling procedure will be conducted for a period of 3000 hours of test time for each group of transformers. After the completion of testing, the statistical significance of the failure rates of each group of transformers will be evaluated.

6.4 INSULATION RESISTANCE

Insulation resistance test to comply with MIL-T-27. The following measurements shall be taken:

a. primary to shield and core
b. core to shield
c. secondary to primary, shield and core

6.5 INDUCTANCE AND LEAKAGE INDUCTANCE

Inductance and leakage inductance tests to comply with MIL-T-27. Leakage inductance shall be referenced to the primary with the secondary shorted.

6.6 TURNS RATIO

Turns ration is measured in compliance with MIL-T-27.

6.7 ELECTROSTATIC SHIELD TEST

The electrostatic shield test shall comply with the test requirements of MIL-T-27.

Table 1: Transformer Configuration

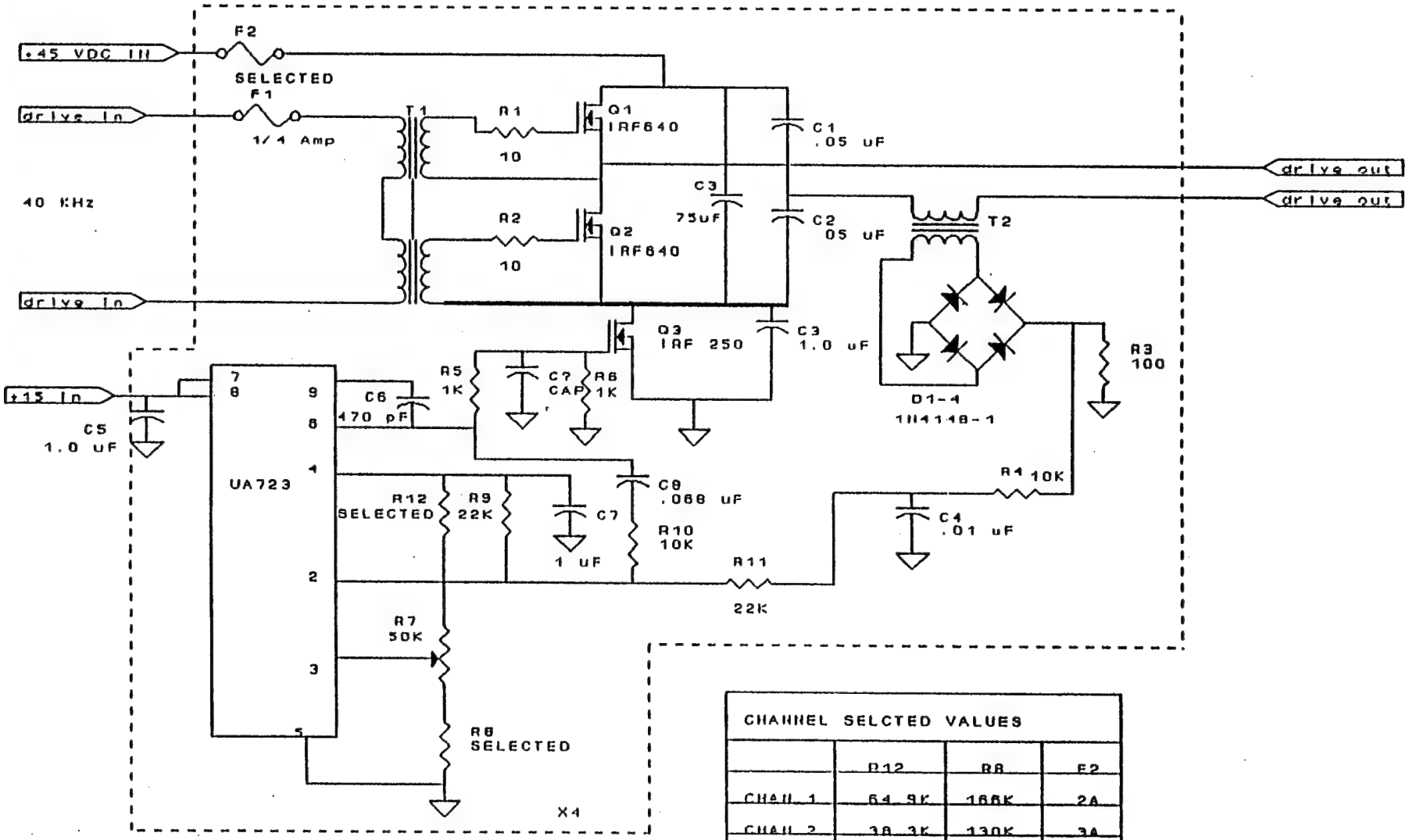
The following information shall be recorded for each sample during and immediately after the build procedure as applicable. The data sheet included in Drawing 159-000676 shall be used for this purpose.

SERIAL NUMBER
DRAWING NUMBER (SPECIFICATION)
DRAWING NUMBER (PROCEDURE)
REVISION
PRIMARY WINDING DATE
PRIMARY WINDING OPERATOR
PRIMARY POTTING DATE
PRIMARY POTTING OPERATOR
PRIMARY POTTING MATERIAL
PRIMARY POTTING PROCEDURE
PRIMARY POTTING DATE CODE/LOT NUMBER
SECONDARY WINDING DATE
SECONDARY WINDING OPERATOR
SECONDARY POTTING DATE
SECONDARY POTTING OPERATOR
SECONDARY POTTING MATERIAL
SECONDARY POTTING PROCEDURE
SECONDARY POTTING DATE CODE/LOT NUMBER
LEAKAGE INDUCTANCE
TURNS RATIO
ELECTROSTATIC SHIELD TEST (OPEN AND SHORT)
LEAKAGE RESISTANCE MEASUREMENTS (3 TESTS)

Table 2 - Transformer Test Data

The following test data is to be recorded after the sample build procedure is complete per Drawing 159-000676 and at the completion of each 100 thermal cycles.

SERIAL NUMBER
ACCUMULATED THERMAL CYCLES
THERMAL CYCLE TEST (PASS/FAIL)
CIV
CEV
TEST DATE
CORONA DATA FILE NAME
CORONA TEST VOLTAGE
PICO-COULOMBS.CHANNEL
TOTAL COUNTS
TOTAL CURRENT
PRIMARY WINDING RESISTANCE
SECONDARY WINDING RESISTANCE
PRIMARY INDUCTANCE
INSULATION RESISTANCE (3 TESTS)
DIELECTRIC WITHSTAND



CHANNEL SELCTED VALUES			
	R12	R8	F2
CHAN 1	64.9K	168K	2A
CHAN 2	38.3K	130K	3A
CHAN 3	38.3K	130K	3A
CHAN 4	TBD	TBD	3A

Figure 1 - Inverter and Controller for 40kHz Excitation

Size	Document Number	REV
A	MANTECH INVERTER AND CONTROLLER	
Date: March 20, 1991	Sheet of	

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

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1.3.2 High Voltage Insulation Systems

AC LOSSES IN HV TRANSFORMER INSULATION

One of the most important electrical properties of encapsulant materials for HVPSs is its AC loss, often referred to as its dissipation factor. When a conductor carrying AC current is encapsulated, some of the power that it is transmitting is dissipated in the encapsulant material. The mechanism for this loss is the coupling of the AC fields surrounding the conductor with the dipoles present in the polar portions of the encapsulant materials, and with the polarizable electron clouds that surround unsaturated chemical bonds in the material. Hydroxyl groups, ether linkages, carboxyl and carbonyl groups, amines, phenyl rings, and many other molecular moieties contain dipoles or polarizable electron clouds that give rise to electrical losses when AC fields are present. AC losses are also a sensitive function of temperature, and should be measured over a range of temperatures. Different polymers will exhibit very different AC loss behavior over temperature, with some showing small changes in loss as temperature increases from ambient to around 80°C or so, while other show changes as large as a factor of five. A study of these phenomena is reported in Volume 3, section 2.3, of this report.

These losses represent real power losses in the encapsulated components or circuitry. Furthermore, the power lost from the electrical circuit is absorbed by the polymer, and this results in heating of the encapsulation material. All other factors being equal, a polymer with smaller AC losses is to be preferred to one with larger AC losses. AC losses are probably most important for transformer impregnant materials, since electric fields are strong in the transformer, and the relatively high level of power dissipation lowers the efficiency of the transformer, and the dissipated power absorbed by the impregnant heats the transformer during operation. The mechanical and thermal design of the transformer and its heat sink will be influenced by the dissipation factor of the material selected as an impregnant. In any case, knowing the dissipation factor of the impregnant and encapsulant materials is of significance in HVPS materials selection, thermal analysis and thermal design, component selection, and in the calculations that yield the projected power output of a particular HVPS electrical design.

A convenient way to measure AC loss is to construct an MTS in the form of a simple transformer that will be impregnated with the encapsulation material to be studied. This MTS is discussed in Volume 3, section 2.3, of this report. The test fixture and test procedure that we used with this MTS, and one that could be used with a wide variety of other AC loss MTSs, are discussed below. Special requirements for the test fixture included:

1) Fixture losses over the frequency and temperature ranges should not distort or obscure the corresponding values of the MTSs being measured.
2) Fixture losses should be known over the range of measurement conditions.

The test fixture, shown in Figure 1, is a metal box containing isolated BNC connectors which may be selectively grounded to the box using individual switches. The purpose of such switching is

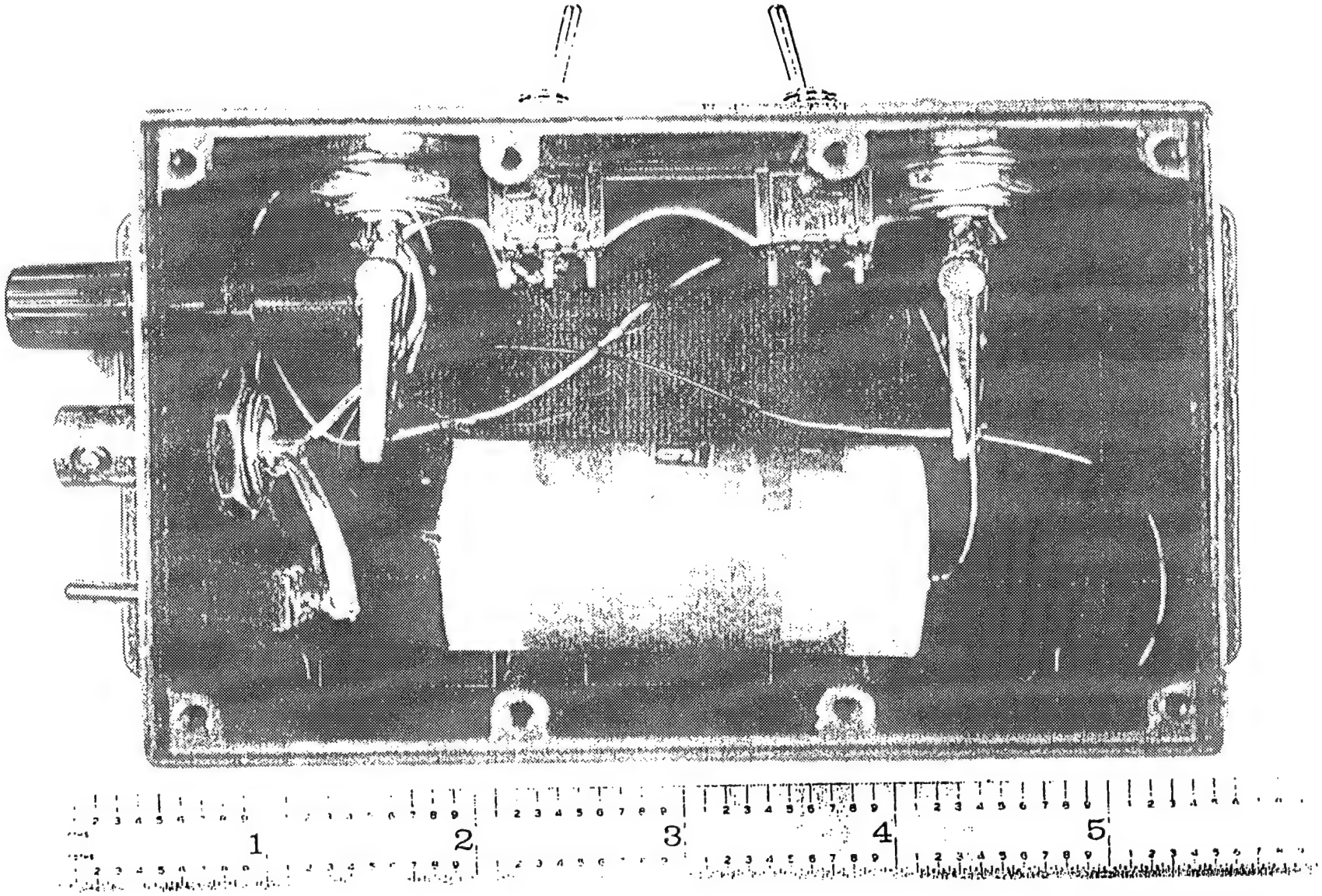


Figure 1. Test Fixture For Measuring The AC Losses Of Transformer Impregnated Coil MTSs At Elevated Temperatures

to permit control over the coupling capacitances and their attendant AC losses. The isolated BNC connectors used were Teflon insulated, to minimize losses at elevated temperatures. For measurements at elevated temperatures, this fixture would be placed in a temperature chamber and connected to a measuring unit via coaxial cables.

The cabling out of the temperature chamber was semirigid coaxial cabling having Teflon insulation and a rated impednace of 50 Ohms. This cabling was connected to the RLR meter using RG-58 coaxial cables. The total cable length was approximately two feet.

The loss measurements for this fixture were performed using a two-terminal configuration. Previous AC loss measurement comparing two and four terminal configurations showed equivalent results over the frequency range used in these studies. The LRC meter was an HP 4291A, having a frequency range of 5 Hz to 13 Mhz and a dissipation factor resulotion of 0.0001. All measurements were made at 1.0 V rms.

AC losses in the cables and test fixture, at the temperatures of interest, must be characterized and subtracted from the total losses measured with the transformer MTS using the same cables and test fixture. This can be accomplished by measuring several standard test items both with the designed fixture, and with a commercial test fixture. Three standard types of samples were selected:

1) Air variable capacitor, APC 100L, 100 pF
2) Silver mica capacitor (per Mil-C-39001), 1.2 nF, 500 V
3) A control-coil MTS similar to those to be evaluated. It was constructed on a fiberglass winding tube, with two windings separated by two polymat layers, and was encapsulated using Epon 825/HV.

The capacitors were chosen because of their low dissipation factors over the frequency range of interest. To establish the AC loss characteristics of the candidate test fixture, both the capacitors and the MTS control were first measured in the designed test fixture and were then measured using an HP test fixture, No. 16047A. Both measurements were made using th HP LRC. The results of these measurements are presented in Table 1. These measurements were all performed at room temperature.

Frequency (kHz)	Ag Mica Capacitor Hughes	Ag Mica Capacitor HP 16047A	Control Coil MTS Hughes	Control Coil MTS HP 16047A	Air Capacitor Hughes
1.0	-0.0004	-0.0004	0.0056	0.0056	-0.0009
10.0	0.0004	0.0003	0.0128	0.0128	-0.0004
50.0	0.0004	0.0004	0.0193	0.0194	0.0000
100.0	0.0006	0.0004	0.0217	0.0217	0.0001
200.0	0.0006	0.0003	0.0238	0.0236	0.0002
500.0	0.0010	0.0004	0.0262	0.0257	0.0003
1000.0	0.0024	0.0006	0.0309	0.0293	0.0007

Table 1. A comparison of the dissipation factors for three standard samples using the Hughes test fixture and the HP test fixture.

Table 2 compares the difference in dissipation factors for the three standard samples measured with the designed test fixture and the HP test fixture. In each case, the difference is expressed as the dissipation factor measured using the designed test fixture minus the dissipation factor measured using the HP test fixture. These measurements were made at room temperature. . These results indicate that the designed test box is suitable for use with low-loss MTSs (loss factors less than 0.0010) at frequencies between 200 and 400 KHz. For items whose loss factors are 0.005 and greater, the designed test fixture is useable from 500 KHz to 1 MHz, depending on the specific loss values. If correction factors are developed such as those shown in Table 2, the designed test fixture becomes useable up to 1 MHz regardless of the loss levels of the test devices.

Tables 3 and 4 summarize the AC capacitances and dissipation factors for the epoxy-impregnated control coil MTS and the silver mica capacitor respectively.

	Ag Mica Capacitor	Control Coil	Air Capacitor	Average Difference
Frequency (kHz)	DF Hughes - DF HP	DF Hughes - DF HP	DF Hughes - DF HP	C1=DF Hughes - DF HP
1.0	0.0000	0.0000	0.0002	0.0001
10.0	0.0001	0.0000	0.0001	0.0001
20.0	0.0001	0.0000	-	0.0000
50.0	0.0000	0.0001	0.0000	0.0000
100.0	0.0002	0.0000	0.0001	0.0001
200.0	0.0003	0.0002	0.0002	0.0002
300.0	0.0004	0.0002	-	0.0003
400.0	0.0005	0.0004	-	0.0004
500.0	0.0007	0.0005	0.0004	0.0004
600.0	0.0009	0.0007	-	0.0008
700.0	0.0011	0.0008	-	0.0009
800.0	0.0013	0.0011	-	0.0012
900.0	0.0016	0.0012	-	0.0014
1000.0	0.0021	0.0016	0.0005	0.0014

TABLE 2. Dissipation Factor Differences Resulting using the Hughes Test Fixture and the HP 16047A Test Fixture for the Ag mica Capacitor, the Control Coil MTS, and the Air capcitor (in each case Difference = D.F. Hughes - D. F. HP).

Frequency (kHz)	Capacitance (pF) Hughes Fixture	Capacitance (pF) HP16047A Fixture	Dissipation Factor Hughes Fixture	Dissipation Factor HP 16047A Fixture
1.0	483	483	0.0056	0.0056
10.0	477	478	0.0128	0.0128
20.0	474	475	0.0158	0.0158
50.0	469	470	0.0193	0.0194
100.0	465	465	0.0217	0.0217
200.0	461	461	0.0238	0.0236
300.0	459	458	0.0248	0.0246
400.0	458	457	0.0257	0.0253
500.0	458	457	0.0262	0.0257
600.0	459	456	0.0270	0.0263
700.0	460	457	0.0278	0.0270
800.0	462	457	0.0288	0.0277
900.0	464	458	0.0297	0.0285
1000.0	467	460	0.0309	0.0293

Table 3. The Resulting Capacitances and Dissipation Factors for the Control Coil MTS using the Hughes Test Fixture and the HP16047A Test Fixture.

Measurement Conditions: 1.0 Vrms, 24°C, 52% R.H., HP LRC meter, Model 4192.

Frequency (kHz)	Capcitance (pF) Hughes	Capcitance (pF) HP16047A	Dissipation Factor Hughes	Dissipation Factor HP16047A
1.0	1.300	1.300	0.0004	0.0004
10.0	1.299	1.300	0.0004	0.0003
20.0	1.299	1.300	0.0003	0.0002
50.0	1.299	1.299	0.0004	0.0004
100.0	1.299	1.299	0.0006	0.0004
200.0	1.300	1.300	0.0006	0.0003
300.0	1.301	1.300	0.0007	0.0003
400.0	1.303	1.301	0.0008	0.0003
500.0	1.306	1.302	0.0010	0.0003
600.0	1.309	1.304	0.0013	0.0004
700.0	1.313	1.306	0.0015	0.0004
800.0	1.318	1.308	0.0018	0.0005
900.0	1.323	1.311	0.0021	0.0005
1000.0	1.329	1.314	0.0024	0.0005

Table 4. The Resulting Capacitances and Dissipation Factors for the Silver Mica Capacitor (per Mil-C-39001) using the Hughes Test Fixture and the HP16047A Test Fixture.

Measurement Conditions: 1.0 Vrms, 24°C, 52% R.H., HP LRC meter, Model 4192.

The new test fixture was then characterized for its loss properties over the combined ranges of temperature and frequency. For this characterization, the air capacitor was chosen, since it should exhibit a nearly constant dissipation factor at each frequency over the temperature range of interest, from ambient to about 125 degrees C. Any deviation from the room temperature values may be considered attributable to differences in the designed test fixture, and not in the air capacitor. Such differences would be used as a secondary correction factor, C2, where C2 would be the dissipation factor at the measured frequency and temperature minus the dissipation factor at the same frequency and room temperature. The results of these analysis are presented in Table 5. These results show that the new test fixture is quite insensitive to temperature in the temperature range studied, and is therefore suitable for studies of the temperature dependance of materials and components AC loss characteristics.

Finally, the AC loss characteristic of four HV insulation materials using MTSs similar to the control coil were determined.

- Epon 825/HV - polymat
- Araldite Cy 9729 - polymat
- Ricotuff LV - polymat
- Scotchcast MR 283/U000 - polymat

These measurements were made over the full range of frequencies, and at three temperatures: -24C, 85C, and 126C. Measurements were made on two(2) MTS'S for each of the HV insulation systems. The results of the measurements are summarized in the accompanying graphs. Of special interest is the fact that, while Epon 825/HV had the highest AC losses at 24C, at higher temperatures the situation was reversed, with Epon 825/HV having the lowest losses between 1 kHz and 500 kHz at 85C, and the lowest losses over the entire frequency range up to 1 Mhz at 126C. AC losses, and their temperature dependance, are strong functions of the chemistry of the polymer.

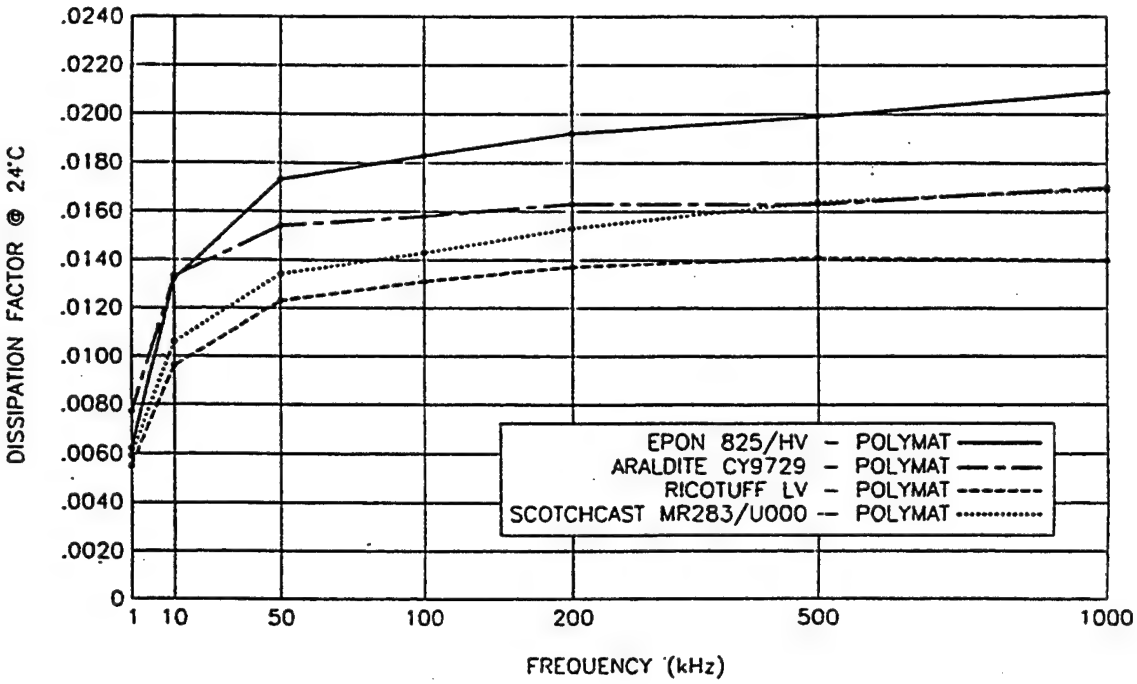
Temp. (°C)	Freq. (KHz)	D.F. Measured	D.F. @ 24° C	D.F. Correction C2
24°	1.0	-0.0009	-0.0009	0.0000
	10.0	-0.0004	-0.0004	0.0000
	50.0	0.0000	0.0000	0.0000
	100.0	0.0001	0.0001	0.0000
	200.0	0.0002	0.0002	0.0000
	500.0	0.0003	0.0003	0.0000
	1000.0	0.0007	0.0007	0.0000
65°	1.0	-0.0009	-0.0009	0.0000
	10.0	-0.0004	-0.0004	0.0000
	50.0	0.0001	0.0000	0.0001
	100.0	0.0002	0.0001	0.0001
	200.0	0.0002	0.0002	0.0000
	500.0	0.0004	0.0003	0.0001
	1000.0	0.0007	0.0007	0.0000
85°	1.0	-0.0008	-0.0009	0.0001
	10.0	-0.0003	-0.0004	0.0001
	50.0	0.0002	0.0000	0.0002
	100.0	0.0001	0.0001	0.0000
	200.0	0.0002	0.0002	0.0000
	500.0	0.0003	0.0003	0.0000
	1000.0	0.0007	0.0007	0.0000
106°	1.0	-0.0007	-0.0009	0.0002
	10.0	-0.0003	-0.0004	0.0001
	50.0	0.0001	0.0000	0.0001
	100.0	0.0002	0.0001	0.0001
	200.0	0.0002	0.0002	0.0000
	500.0	0.0004	0.0003	0.0001
	1000.0	0.0007	0.0007	0.0000
127°	1.0	-0.0007	-0.0009	0.0002
	10.0	-0.0003	-0.0004	0.0001
	50.0	0.0002	0.0000	0.0002
	100.0	0.0001	0.0001	0.0000
	200.0	0.0002	0.0002	0.0000
	500.0	0.0004	0.0003	0.0001
	1000.0	0.0008	0.0007	0.0001

All measurements at 1.0 VRMs

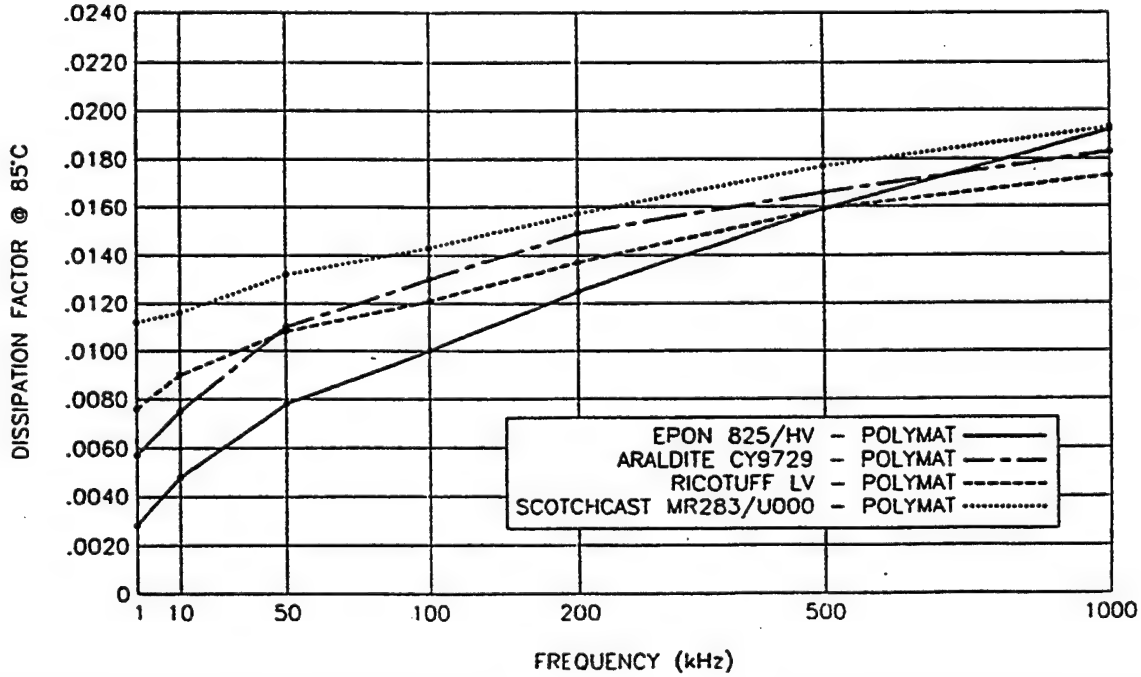
TABLE 5

Dissipation Factors for the Variable Air Capacitor (APC 100L) as a Function of Temperature and Frequency using the Hughes Test Fixture

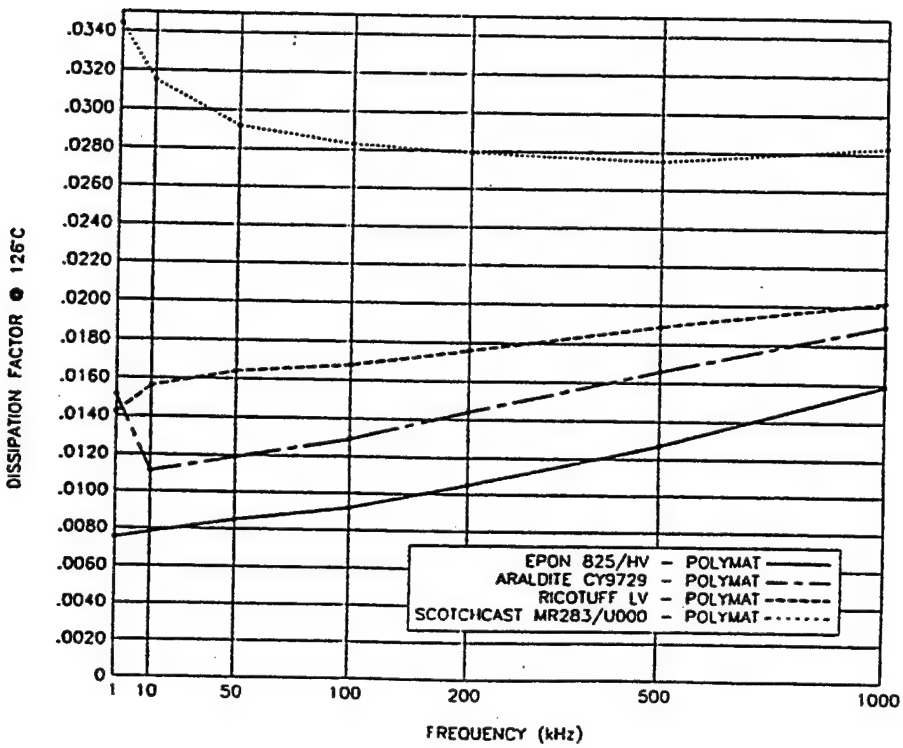
DISSIPATION FACTORS OF MTS'S AT 24°C



DISSIPATION FACTORS OF MTS'S AT 85°C



DISSIPATION FACTORS OF MTS'S AT 126^0



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1.4.1 Life Test Procedure

1.0 SCOPE

This document defines the life test requirements and procedures for the high voltage 12-pin electrical connector assemblies listed in paragraph 3.2.

2.0 PURPOSE

The prime purpose of this test is to investigate aging characteristics of high voltage connectors due to repeated electrical and environmental stress screening. In addition, the procedure will aid in the investigation of two connector assembly methods (bonded and slip fit) as well as an investigation of correlation between corona characteristics and life.

3.0 DOCUMENTS

Use the latest issue of drawings and specifications in effect or as specified herein.

3.1 Test Standards

MIL-STD-1344	Test method for electrical connectors
MIL-STD-202	Test method for electronic and electrical component parts
MIL-STD-45662	Calibration system requirements
ASTM-D-1868	Standard method for detection and measurement of partial discharge pulses

3.2 Northrop ESD Drawings

010-005826	HV 12 position electrical plug connector
010-005896-002	HV 12 position electrical receptacle connector

3.3 Reynolds Industries Inc. Drawings

178-9077	12 pin plug assembly (Advanced Series)
178-7490	12 pin receptacle assembly (Advanced Series)
178-0037	Cable preparation
SK052391-941	Plug assembly, 12 pin, bonded
SK052391-942	Plug assembly, 12 pin, slip fit
SK060591-945	Cable preparation
T-7265-1	Vacuum plate
T-7265-2	Column
T-7265-3	Ground plate

4.0 TEST EQUIPMENT

Substitute equipment may be used provided such equipment is of equal or greater accuracy. Test equipment calibration shall comply with the requirements of MIL-STD-45662.

Environmental Test Chamber
Thermotron
Model No.: EL-8-CH-2-2-5
Serial No.: 21-8048
Calibration: 6 mos.
Range: -73 C to 200 C

Corona Detection System
Biddle
Sys. No.: 663040-01
Serial No.: 1791
Calibration: 6 mos.
Range: 0 pc-1000 pc
.1 - 75kVdc
.2 - 40kVac

Data Recorder
Tracor Westronics
Series 2100
Serial No.: 1234
Calibration: 6 mos.

LCR Meter
Hewlett Packard
Model No.: 4261A
Serial No.: 1821JU03445
Calibration: 6 mos.
Range: L: .1 uH - 1000 H
C: .1 pf - 10.00 mf
R: 1 m - 9.99 M

Megohmeter
General Radio
Model No.: 1863
Serial No.:
Calibration:
Range:
.5X10E3 -20X10E12 MEG
50,100,200,250,500V

Picoammeter
Keithley
Model No.: 485
Serial No.: 438319
Calibration: 12 mos.
Range: 2nA - 2mA

Altitude Gauge
Tenney Duragauge Data
Model No.: 1850
Serial No.: N/A
Calibration: 6 mos.
Range: 1K - 80K feet

Multichannel Pulse
Height Analyzer
Nuclear Data
Model No. ND65B
Calibration: Daily
via corona detector
Range: 0-8V; 256 to
4096 channels

5.0 TEST SAMPLE

5.1 Sample

A test sample shall consist of a mated pair of connector assemblies per para. 3.2. (Note: each plug connector consists of a multiple assembly holder and 12 subassemblies).

5.2 Sample Preparation

5.2.1 Bonded plug assemblies shall be prepared per the requirements of drawing SK052391-941. Slip Fit plug assemblies shall be prepared per the requirements of drawing SK052391-942.

5.2.2 Receptacles shall be prepared as deadhead connectors.

5.3 Sample Acceptance Test

5.3.1 Plug connector assemblies shall be tested as they would be for normal application per the requirements of Northrop ESD drawing No. 010-005826-002, note 4.0.

5.4 Sample Inspection

Plug and receptacle connector assemblies shall be inspected visually and mechanically for conformance to the requirements of drawings per paragraph 3.2.

6.0 TEST SET-UP

6.1 Thermal Cycle Test Set-Up

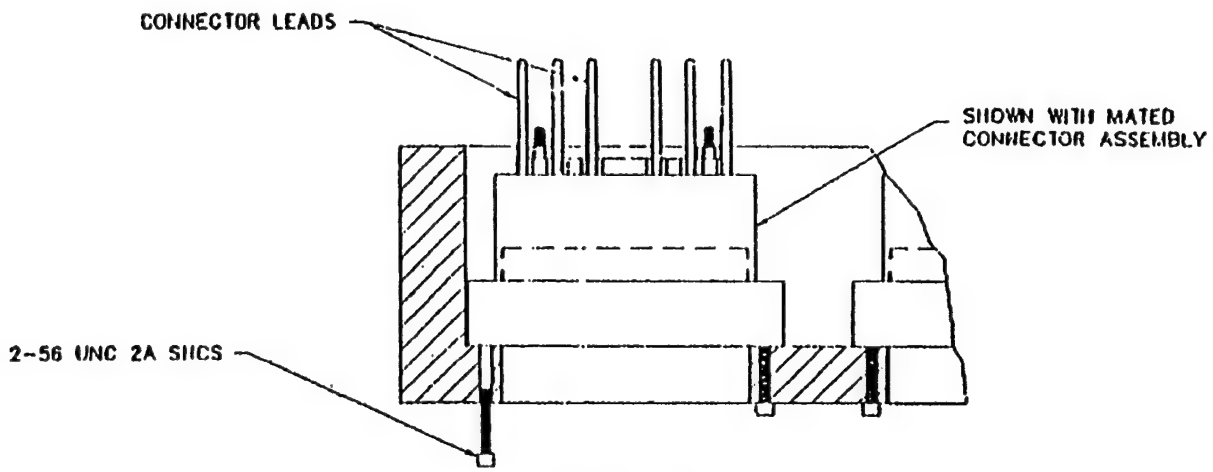
Mate plug connector assembly to receptacle connector deadhead. Load the mated pair onto the column as shown in figure 1 (Note: The test fixture assembly consists of four columns permanently attached to the vacuum plate to form one continuous unit, as shown on figure 2). Drop potted end of the receptacle connector into column cavity first. The flanges of the connector should rest against the bottom of the cavity. Enough clearance is available to allow movement of the mated assembly for proper alignment of the molded-in threaded inserts in the connector with the through holes on the column. Loosely fasten the mated pair at the back end of the column using 2-56 UNC 2A socket head cap screws. Repeat this process for every connector being placed on the test fixture. Install the ground plates on both sides of the mated connectors. Secure the plates firmly against connector walls using 1/4-20 UNC 2A socket head cap screws to be threaded through the side walls of the column as shown on figure 1. Ground leads should be attached to ground plates using nut/washer arrangement as shown. Finally, using a suitable tool, hand tighten the 2-56 screws to secure the mated assemblies. Once completed, the assembled unit will be placed into the vacuum tank and sealed as shown in figure 3. The tank will then be loaded into the environmental test chamber (Thermotron) and all leads connected to required test equipment.

6.2 Insulation Resistance Test Set-Up

The test fixture assembly along with ground plates and mated connectors will be removed from the vacuum tank and placed on a test bench for insulation resistance testing. Tests will be performed independently on each pin per paragraph 7.2.

6.3 Partial Discharge Test Set-Up

The test fixture assembly along with ground plates and mated connectors will be loaded into the corona test chamber (Biddle) for partial discharge testing. Tests will be performed independently on each pin per paragraph 7.3.



VIEW A–A

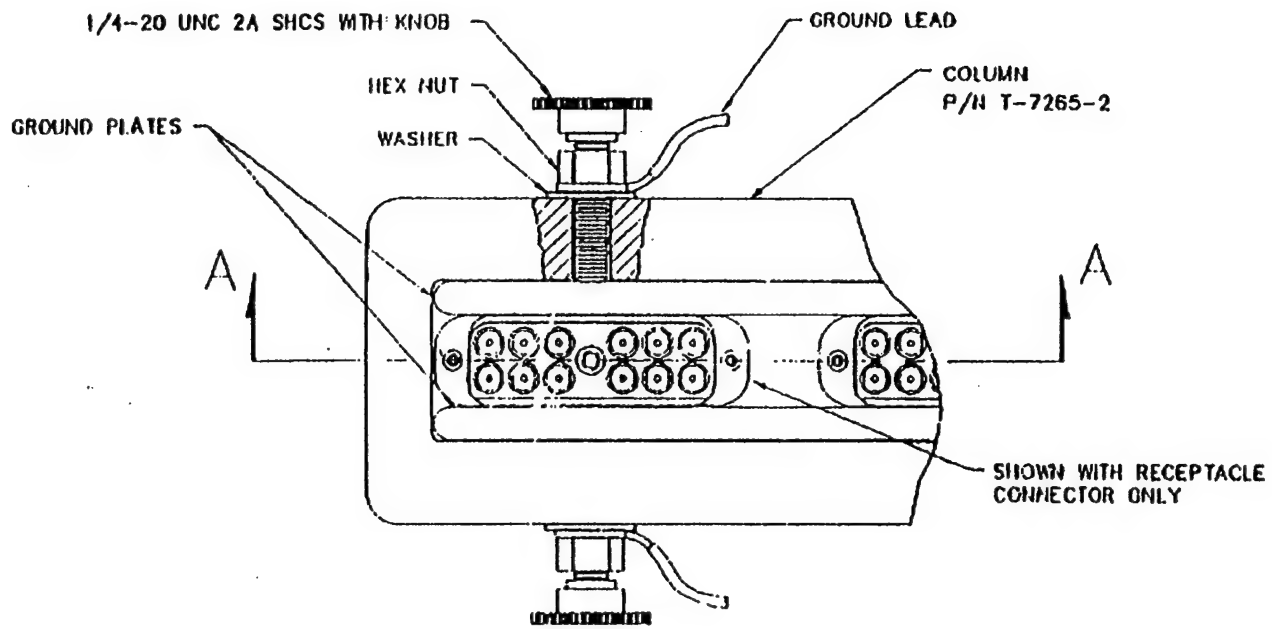


FIGURE 1

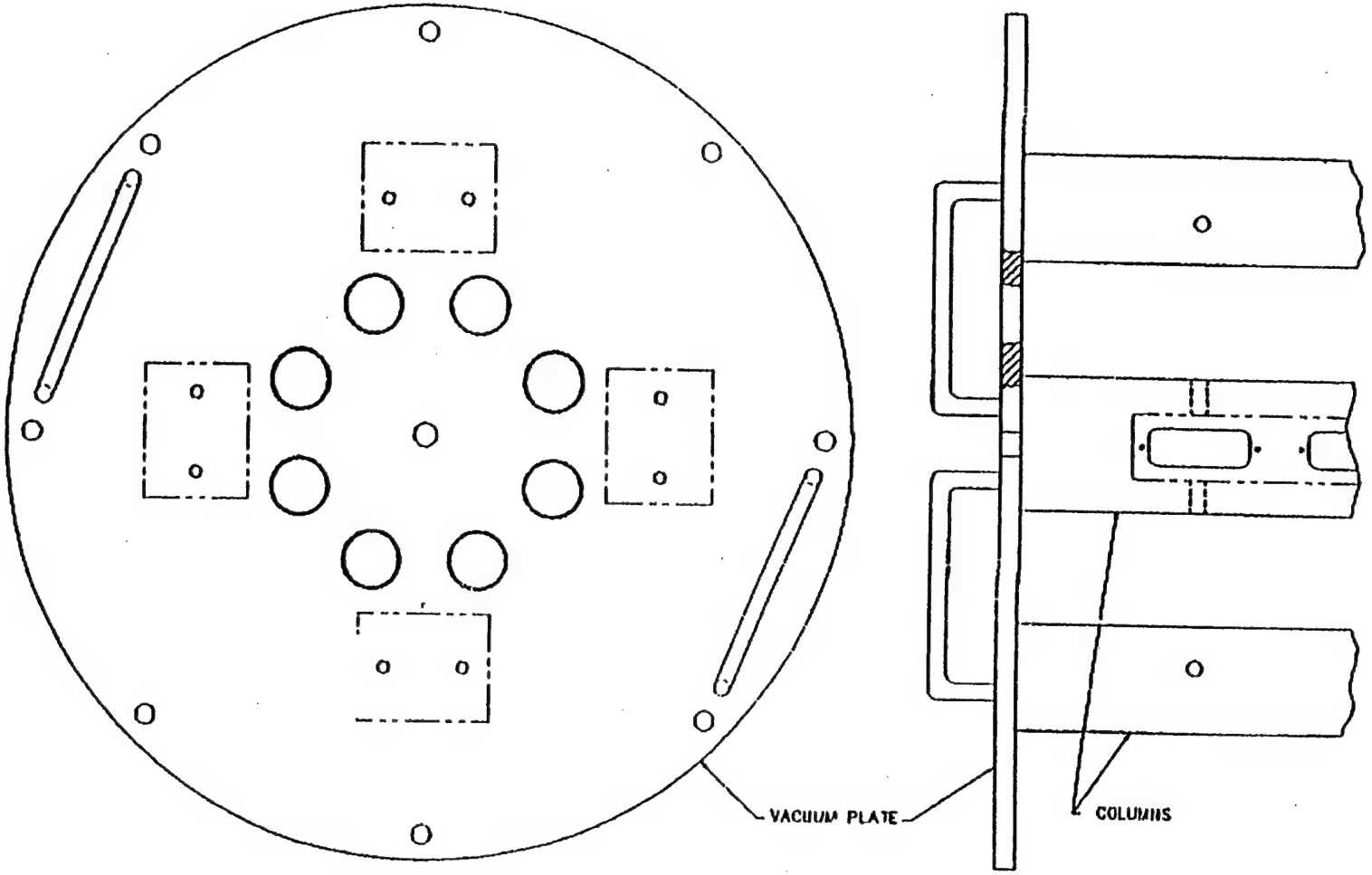


FIGURE 2

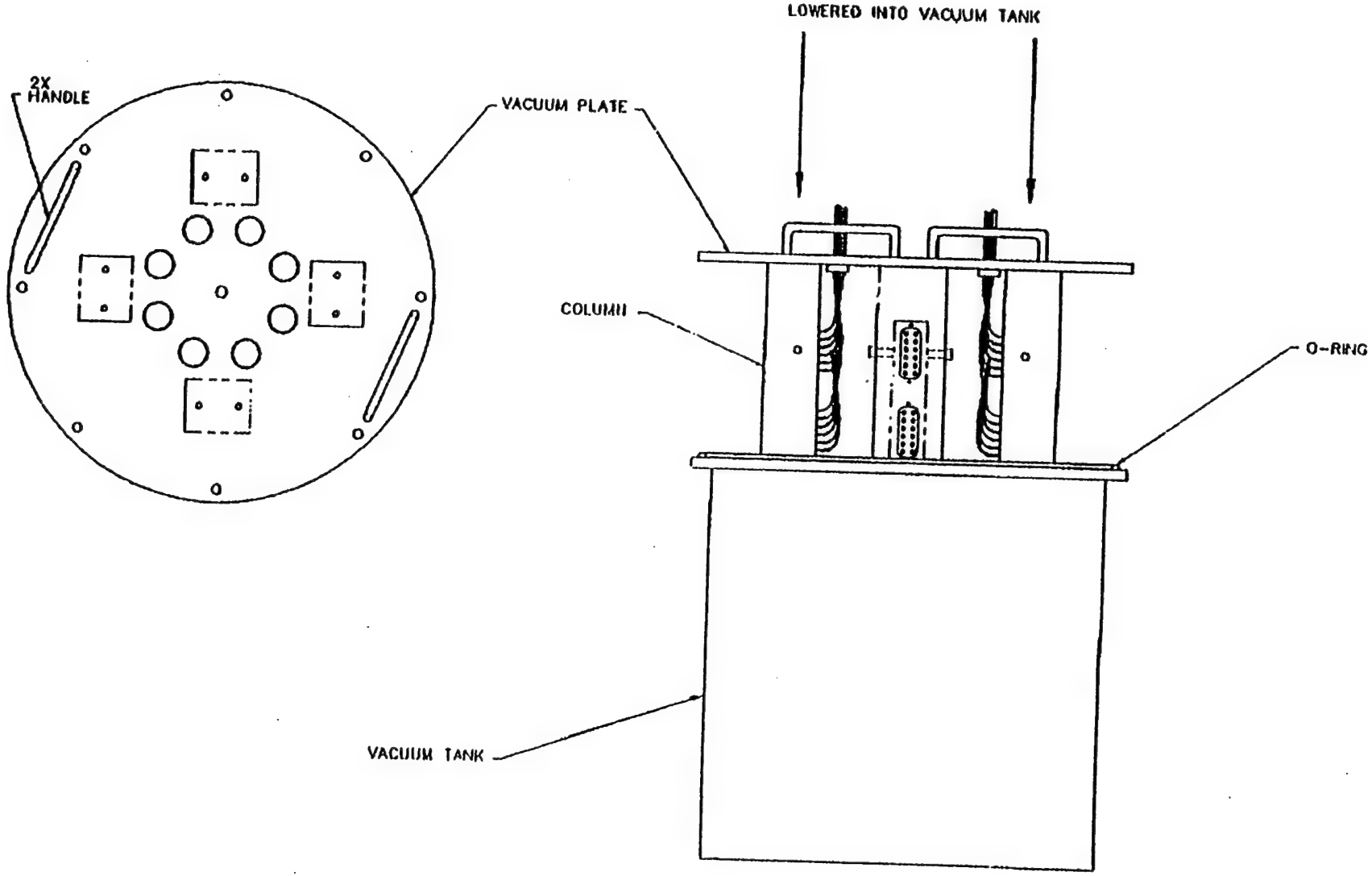

2X
HANDLE
VACUUM PLATE
LOWERED INTO VACUUM TANK
COLUMN
O-RING
VACUUM TANK

FIGURE 3

7.0 TEST PROCEDURE (Steps to be performed in the order shown)

7.1 Contact Resistance

7.1.1 Contact resistance test to comply with MIL-STD-1344, method 3004.1.

7.1.2 Install male contact P/N 178-0668 (of known resistance) into socket contact at front of plug assembly.

7.1.3 Connect the milliohm meter probes to corresponding lead center conductor on plug assembly and male contact solder pot. Measure and record the contact resistance (Note: The resistance of connector lead and male contact must be subtracted from total measured resistance to obtain actual plug contact resistance). Repeat this procedure for each of the 12 contacts in the plug assembly.

7.2 Insulation Resistance

7.2.1 Insulation resistance test to comply with MIL-STD-1344, method 3003.1.

7.2.2 With parts mated and assembled per paragraph 6.0, measure and record insulation resistance between contact and ground plate. Test each contact independently while all other contacts are grounded. Repeat this procedure for all 12 contacts.

7.3 Partial Discharge

7.3.1 All partial discharge measurements will conform to the procedures of ASTM D-1868-81 Standard Method for detection and measurement of partial discharge (corona) pulses.

7.3.2 All measurements will employ the basic circuit of ASTM D-1868-81, Figure 1, Circuit No. 1.

7.3.3 These measurements will utilize the Biddle Partial Discharge System (Spec. No. 663040) presently installed at the Los Angeles plant of Reynolds Industries, Inc.

7.3.4 A separate measurement will be made for each pin on every connector in the test group. During this time, all other pins will be grounded.

7.3.5 Corona inception voltage (CIV) and corona extinction voltage (CEV) will be measured at 60 hertz. In addition, similar data will be obtained under direct voltage (e.g., after one minute dwell time at 15,000 volts).

7.3.6 DC measurements will employ a Nuclear Data (now Canberra Instruments) ND65B multichannel pulse height analyzer for data acquisition and analysis of the partial discharge

(corona) pulses. It will be calibrated to utilize 512 channels, each representing a 0.5 picocoulomb increment. The amplifier will be made to saturate at about 250 pc, so that any pulses of larger magnitude will still be counted.

7.3.7 For the dc measurements, an individually tailored computer program will be used to control the test timing (including the dwell time at voltage and the measurement time) and the grouping of channels for totaling the pulse count. Results will be printed out as number of counts in each specified picocoulomb energy range and as energy dose rates in picocoulombs per second. Note: The computer will initially be programmed to take measurements over a period of one minute following three minutes dwell at the applied voltage. The number of counts per minute will be recorded over the following picocoulomb ranges: 5-24, 25-49, 50-99 and >100. Total picocoulombs per second, for pulses >5 pc, will also be recorded. This set-up is subject to change after evaluation of initial test results.

7.3.8 Partial discharge tests will be run at 75 degrees +/-5 degrees F. Test chamber relative humidity will be recorded.

7.4 Thermal Cycle

7.4.1 Thermal cycle test to comply with MIL-STD-202, Method 107, Test Condition B-1.

7.4.2 Subject mated assembly to 25 cycles of the following temperature conditions with simultaneous application of 15,000 volts dc continuously at 35 +/-5 TORR (Note: Samples to be tested with no voltage applied will undergo the same sequence of temperature/altitude conditions):

Step 1: Bring mated assembly to -65 + 0/-5 deg. and soak for four hours.

Step 2: Bring mated assembly to 25 +10/-5 deg. C for a maximum of five minutes.

Step 3: Bring mated assembly to 125 +3/-0 deg. C and soak for four hours.

Step 4: Bring mated assembly to 25 +10/-5 deg. C for a maximum of five minutes.

7.5 Insulation Resistance

Repeat paragraph 7.2

7.6 Partial Discharge

Repeat paragraph 7.3.

7.7 Repeat paragraph 7.4, 7.5, and 7.6.

7.8 Repeat paragraph 7.4, 7.5, and 7.6.

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1.5 Diode Test Methods

HV diodes are one of the most critical components in an HVPS. As such, they deserve close attention in the component selection activities of the design process. To assist this process, we have created specific QFD forms to be used for diode selection, that help the multi-functional concurrent engineering team ensure that the diode candidate selected satisfies the key requirements of the HVPS better than does any other candidate. As always, specific engineering data about components is needed to ensure that the QFD forms represent a realistic assessment of the competing component candidates. All of the information required is seldom available from the component manufacturers and even when it is, information from different vendors may not be directly comparable, due to their use of different analysis techniques and the varying quality of their results.

For these reasons, it is generally necessary for HVPS manufacturers to characterize critical components, including HV rectifier diodes. Diode characterizations fall into two general categories - 1) construction reviews (Section 1.5.1) and, 2) electrical and environmental tests and evaluations (Section 1.5.2). In the following sub-sections, we present information on both of these procedures.

Construction reviews of electronic components are important elements of component selection during the design process, and of component lot qualification during manufacturing. They can be used to reveal the internal design of a component, together with its methods and materials of construction, so that a particular component can be compared to other similar components, and its suitability as a candidate for use in the HVPS can be assessed. Construction reviews are also an integral part of component failure analyses that may be performed as part of MTS studies, analysis of failures in EDM units, or in analysis of field returns. Construction reviews can form the basis for a component database that can be used by an HVPS manufacturer in all of component selections that they undertake as a part of their HVPS design or redesign activities.

While components types differ greatly, the construction review methods that are used to study them are remarkably consistent from part type to part type. Furthermore, the guiding principals that underlie all construction reviews are the same in most particulars. In construction reviews, it can be said that one proceeds from the general to the specific, from the broadest overall view of the component to the most minute and detailed view, and from the least destructive procedures progressively through more destructive procedures. In the process, the results of the higher level analyses are used to guide the subsequent, more detailed analyses, and the specific focus of attention can change significantly during the course of the analysis as a consequence of the information uncovered along the way. Therefore, in general, the engineer or skilled technician should review the results of completed procedures before progressing to further procedures.

1.5.1 Construction Review of High Voltage Rectifier Diodes

A Construction Review was performed on 10 diodes. The devices were fast recovery types (Trr under 100ns) and had voltage breakdowns between 600 and 3000 VDC. The units included single and multi-junction types. The documentation that follows gives the definition of a Construction Review, why it is performed, methods and procedures used and gives the details of a review conducted on one of the 10 diodes. This latter review - which is basically a Destructive Physical Analysis - is presented as an example. The choice of vendor Semtech is coincidental. DPAs were also performed on diodes from VMI, Motorola, Phillips, Sensitron and SSDI but are not included for the sake of brevity.

1.0 INTRODUCTION

WHAT is a Construction Review, WHY is it done, and HOW is it performed? This report will provide the answers to these questions, both in general terms and by the specific example of a series of Construction Reviews of several High Voltage (HV) Rectifier Diodes.

The following sections present a general description of the elements of a Construction Review, including the purposes and benefits. This is followed by a description of the review areas for the HV rectifier diodes, including detailed summaries of the analysis methods. The final section is a summary of the reviews for 10 HV rectifier diodes. These devices range in operating voltages from 600 to 3000 volts, and in design from single to multifunction structures. All are fast recovery devices having rated reverse recovery times (t_{rr}'s) of less than 100 nanoseconds. They are intended to represent components, which might be used to construct a high voltage switching power supply. Diodes of this type would be used to construct rectifying bridges capable of operating at 1.0 kV and above, at slightly less than one (1) amp, and at frequencies of 50 kHz and higher.

2.0 ELEMENTS OF A CONSTRUCTION REVIEW

A Construction Review is a process by which selected physical attributes of an item--component or assembly--are characterized. Such characterization can be useful in several ways, including

1--determination of the physical design and materials of construction for an existing product, thereby providing a baseline against which future or

alternative products can be compared. Incoming lots of production parts can be compared to the baseline.

2--identification of key and critical properties in both the physical design and the construction materials. A particular application may have special conditions associated with it which make a particular design either suitable or unsuitable for use.

3--a corollary of item 2,--the identification of existing or potential problems associated with the design or construction materials. Sometimes a vendor can be persuaded to improve his product to satisfy a particular customer requirement, based on the review findings.

4--an information base for use in subsequent failure analyses of the product. Knowing the configuration and construction can save much time and money at a point where time and money are critical.

In order to achieve these benefits, each Construction Review is tailored to specific attributes of the product of interest. Such tailoring should include both the usage requirements and the physical make-up of the product.

A construction review generally involves three (3) areas of evaluation:

1--Destructive Physical Analysis (DPA), which involves the physical characterization of the product both nondestructively and destructively.

2--Quantitative testing and measuring; these are typically tests and measurements not directly

related to operating values, but which assess features that may affect these operating values.

3--Materials characterizations; identification of key and/or critical materials and processes used in constructing the product.

2.1 DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

A DPA follows a specific sequence of steps, beginning with nondestructive and moving successively to increasingly destructive examinations. The sequence of steps is controlled in order to extract the maximum of information from a minimum number of parts. In some cases, such as hybrid microcircuits, individual parts can cost several hundred or even several thousand dollars each. All of the steps in the DPA are documented by the technician(s) performing the tests and the results are assembled into a report for review by the cognizant engineering personnel. In addition to serving as an incoming part examination, the report becomes a history, for use in case of problems with a particular lot of parts, and also for comparison with lots to be received in the future.

Documentation, as mentioned above, generally means photographs, many times in color, of the parts as they progress through the DPA. Generally one takes Polaroid photographs, using professional macro-, micro-, and metallographic equipment, documenting the DPA as it progresses. 35 mm photography, with later processing, is not considered acceptable. In order to reduce film costs, the wave of the future will be video recording and printing of the desired views. Current video resolution and quality is approaching that required on a routine basis.

Typical activities of a DPA can include the following:

Visual and optical observations. These are observations made of the "as received" (from the manufacturer) product. Observations may include--

- proper markings and identifications
- dimensional and configuration conformance
- workmanship
- observable defects
- correct/specified materials

These observations and others as required are nondestructive.

X-ray (and possibly neutron radiographic) Inspections. Both of these techniques provide nondestructive information regarding the internal configuration and construction of the product. Such information can be useful in assessing the internal quality and as a guide for approaching the Cross-sectional examination. Voids, poor alignment, solder balls, etc. are all defects which are found radiographically.

Package Gas Analysis. For devices containing an internal cavity, at this point one frequently has the device punctured and the internal gas analyzed under controlled conditions (MIL-STD 883, Method 1018) to determine the moisture level. This is not applicable to most passive parts or to devices which do not have an internal cavity, such as power diodes.

Cross-sectional Examination. At this level, the physical destruction of the product begins. In the case of microelectronics, destructive analysis began with package gas analysis above. At this point, a detailed plan should be followed to assure that the necessary and desired information is obtained. In the case of microelectronics with an internal cavity, a different path, including internal visual, SEM examination, bond pull, die shear, etc.

is followed. The following pertains specifically to diodes and other similar devices. Analyses and observations during this portion of the DPA include:

- Optical microscopic reviews to determine micro details of construction. Etches may be used to show junctions, metallographic structures, plating layers.

- Scanning electron microscope (SEM) observations for further refinement of micro details, clarification of structures ambiguous to the optical microscope, and the increased depth of field obtained.

- Energy dispersive X-ray (EDX) analysis, an analysis done in the SEM which provides an elemental analysis of areas observable in the SEM, down to about 1 micrometer. For the analysis and identification of the materials of construction.

- Physical measurements, micro and other, of design and assembly detail. To establish conformance to specifications and standards and for use in performance and reliability assessments. These consist of lead diameters, plating thicknesses, weld depths, and other observables which can be measured either optically or in the SEM.

- Other analyses, such as Auger spectroscopy, FTIR spectroscopy, etc. Special analysis requirements are based on the specifics of the product being examined.

2.2 QUANTITATIVE TEST AND MEASUREMENTS

The Quantitative Test and Measurements, as previously noted, are typically determinations which do not relate to the operating or functional values of the product. However, whenever a Construction Review is being performed, it is recommended that an appropriate number of functional measurements be made to establish the operational behavior of the product relative to its requirements or specifications. The results should become part of the Construction Review Summary. Such results define, in part, the quality of the product being reviewed--and may prevent defective or nonconforming product being used to define baselines and standards.

The nonfunctional areas of test and measurements associated with a Construction Review may include:

Dimensional Details. These measurements may range from macro to micro, and may include overall product dimensions, internal dimensions, lead sizes and spacings, plating thicknesses, etc. These are best made at the time of examination, but may be made later from photographs, if magnifications are accurately known.

Selected mechanical property determinations. Examples of such determinations include lead pull strengths, wire bond strengths, shear strengths of dies and bonds, torsional strengths of pins and wire leads, etc. The choice of tests should reflect both the specification or standards requirements and the conditions under which the product is used. In many cases, there are listed both nondestructive and destructive limits; where practical, the destructive limits are tested during the Constructional Analysis. In the case of diodes, it was felt to be impractical to pull

the part to destruction, as the other details of the part would be destroyed.

Process and assembly determinations. Measurements made in this area should reflect the types of assembly methods and/or process conditions which the device or product will experience as it achieves its final form and assembly. Such assembly related test might include solderability and/or weldability determinations; (solder) heat resistance measurements; lead forming and bending determinations; resistance to solvents, where the partially assembled device will be subjected to cleaning. These determinations test the compatibility of the part with any special processes to which it will be subjected during assembly. These tests should take into account any factors not envisioned by the manufacturer of the component, but which would be encountered during fabrication and/or final use.

2.3 MATERIALS CHARACTERIZATIONS

The Materials Characterizations are an integral part of all Construction Reviews. Of prime consideration here is the determination of what materials are to be characterized. As in the other areas of evaluation, these determinations should take into account specification and/or standards requirements as well as the operational end-use performance requirements. The analysis methods to be used will depend on several factors, including

- types of materials
- their amounts and physical location
- susceptibility to alteration or destruction by the DPA process.

Typical characterization methods employed during Construction Reviews include:

- EDX analysis of metals and other inorganics, as well as foreign or contaminating substances, or of fillers in organic formulations

- Conventional chemical methods of analysis, such as FTIR for analysis of organic materials, such as encapsulants, adhesives, coatings, etc., as well as chromatographic analyses, atomic absorption spectroscopy, mass spectrometry of organic materials, as well as package atmospheres.

- Specialized or surface-oriented techniques, such as Auger spectroscopy, ESCA, or similar, where stains or tiny amounts of contaminants are noted. These techniques are also useful where problems of adhesion, contact resistance, or solderability exist.

In performing a Construction Review, the methods discussed above are applied in total or in part to the product under review, with emphasis on the following areas:

- Leads and interconnections (internal and external)

- Packaging materials used in constructing the product

- Active/Functional items of the product

- Process and assembly details.

The extent of the reviews in each of these areas will depend, at least in part, on the purpose(s) intended for the Construction Review.

3.0 A CONSTRUCTION REVIEW FOR HV RECTIFIER DIODES

As noted previously, a Construction Review should include specific goals and purposes. These may include conformance determinations, application and use requirements including assembly and processes, and general information gathering. The latter might be done to provide further information for product comparisons leading to parts selection. The goal identification is quite important, and should be the initial step in the Construction Review of the HV Rectifier Diodes.

For this specific example, diodes are desired to construct a multistage DC power supply. Each stage might be 2000 V or greater and required to deliver up to 0.5 amps. Each stage would consist of full-wave bridges, operated at 50 kHz or even higher frequency to reduce weight. The designer of the supply may wish to use single parts or 3-5 devices in series for legs of the bridge, depending on parts availability, weight and volume allowed for the bridge, power, and other factors. The diodes selected to be reviewed were selected from data sheets of major manufacturers, based on several factors:

- voltage and current ratings--about 1 amp and from 3000 volts (1 diode/leg) to 600 volts (5 or more diodes/leg).

- reverse recovery time. To be operated at the frequency required, diodes must turn on and off quickly to keep power dissipation low

- size, shape, configuration. Axially leaded diodes were chosen. Ceramic bodies, except for a series of

plastic packaged devices chosen strictly for comparison, were the rule.

It is anticipated that the diodes will be soldered together and encapsulated as a series of bridges, and that there will be problems in terms of power dissipation and heat transfer, assembly, and weight in constructing the supply. High reliability will be needed, with a low electrical and mechanical defect rate, low power dissipation (electrical requirement not treated here, except that several diodes in a single package will tend to concentrate power dissipation, a poor feature), with means of getting heat out of the part and to a heat sink (high thermal conductivity leads). Good mechanical properties will be needed to bend and solder these parts into a small package.

With these goals in mind for the Construction Review, a typical review sequence would be as follows:

1. External visual examination, noting
   - o markings
   - o package type and dimensions
   - o lead types and diameter, length
   - o defects, such as cracks, chips, discolorations, lead damage
   - o photographically document devices and defects

2. X-ray inspection for
   - o attachment quality of leads, slugs, die
   - o centering and alignment of leads, slugs, die
   - o package integrity--absence of cracks, voids, porosity
   - o photographically document

3. Lead pull (nondestructive)
   - o to assure the integrity of lead attachments (and, for some designs, the package integrity)
   - o employ manufacturer's or specification test loads and times

4. Solderability of leads (where solderable finishes are present--tin, solder, gold, or silver) or weldability (nickel or gold-plated nickel)
   - o for solderability, use MIL-STD 202, Method 208, unless an alternate is specified
   - o for weldability, use the specified standard
   - o appropriately record results. In the case of poor solderability, a photo showing the results is desired.

5. Transverse cross-sectioning of leads for the purpose of
   - o identifying lead type, material, diameter
   - o determining any metal finishes, including cladding, platings, coatings.
   - o examining uniformity and quality of the above, seeing defects, such a stringers, blistering, etc.
   - o in order to see thin layers, the lead should be overplated with a hard metal, such as nickel, for edge retention during sectioning.
   - o photodocument to show diameter and type. Higher magnification will be needed to see and measure metal finishes.

6. Longitudinal cross section of diode and examine optically to examine
   - o lead attachments, including type of attachment, positioning, quality
   - o die attachments (see above) and number of dies

- other attachments, such as slugs, springs, arrows, etc. for materials, attachment methods and quality, and alignment
- package material for type, coverage and protection, cracks, porosity, general quality
- dies, including number, type, integrity (absence of cracks and chip-outs), passivation
- die (after etching) to identify and characterize junctions
- photographically document the above, including notation of all defects and anomalies

7. SEM/EDX examination of cross sections. The cross sectioned part should be further examined in SEM, used in combination with EDX analysis to characterize and identify materials
   - lead material, platings, and coatings
   - slugs, springs, or other internal parts, including examination for platings or coatings not optically seen
   - all braze, weld, and other joints, including die-slug and die-die joints
   - package materials, particularly ceramics and glasses, including interfaces with leads and slugs. For plastic packages, FTIR can be used to identify material types.
   - documentation to include photos with various materials marked and EDX spectra of those areas

From these Reviews, should the manufacturer change the number of dies, the method of lead attach, or any one of dozens of details, the Construction Review will show new parts to differ from the historical record and allow the new lot of parts to be flagged for engineering review of the change(s). In addition, material or workmanship problems, such as cracks or porosity, poor lead attach, etc. would be

found and remedial action taken before problems appear on the production line or in the product.

It should be noted that the three (3) topical areas of a Construction Review, discussed in Section 2.0, have been integrally combined in the Construction Review of the HV Rectifier Diodes. This type of combining of the areas will be typical of most Construction Reviews.

4.0 PROCEDURES AND METHODS USED IN THE CONSTRUCTION REVIEWS OF THE HV RECTIFIER DIODES

This section presents in sequence form the methods employed in performing the Construction Reviews on ten (10) HV Rectifier Diodes. Included are the general methods, including notations of the equipments used in these evaluations. The evaluation sequence for each diode follows:

1--Record part markings and serial numbers. If the parts are not serialized, use wire markers to tag each part with arbitrary numbers so that any anomalies seen in one section of the Review (such as a void seen in X-ray) could be tracked and noted later (as a void seen in cross-section). Using a macro camera, such as the Polaroid MP-4, photograph the three diodes as a group at appropriate magnification, so that typical visual characteristics (shape, leads, markings, chipping, damage) can be seen by the viewer. Record the magnification.

2--Record X-ray images of the parts as a group at 2 orientations 90° apart, rotated about their axes (leads). This can be done by first setting the exposure (kV and time) using Polaroid film to achieve good contrast between the case, dies and die

attachment. The slugs and leads may be totally underexposed. The two desired views can be recorded on a single 4 x 5 sheet of regular (wet processed) X-ray film for archiving by alternately exposing half the film (blocking the other side with a sheet of lead). Make a blow-up of any defects, using a light box and macro camera.

3--Perform the solderability test, using Sn63 solder (QQ-S-571), according to MIL-STD 202, Method 208. This method covers the entire procedure, which involves dipping the lead into molten solder at 245°C. If the lead fails to tin well (smooth, shiny, unbroken surface), photograph the results with a macro camera at appropriate magnification (10X-20X) to show up the anomalies.

4--Perform bond pull to a 5 lb. maximum load. Typically, a Chatillion pull tester is used, which is slightly more sophisticated than a fish scale, which could be used, if it had been calibrated. The object at this step is to demonstrate the integrity of the body and lead attachments, showing that the parts are not going to break during lead forming or other assembly operations. All parts should pass without a problem, and the Review requires only a notation of the stress level and whether the parts passed or failed.

5--Remove a lead from 1 part and overplate with ca. 0.001" of nickel. Embed the part in a standard mounting resin for cross-sectioning. Section transverse to the lead direction and photograph using the metallograph to record the lead diameter (at ca. 100X), and higher as appropriate to show lead grain structure (after appropriate etching),

platings, and/or solder coating. A magnification of 1000X may be needed for the last step, as thicknesses of 0.0001" are possible.

6--(Simultaneous with 5) Embed two (2) of the diodes separately in clear mounting resin and cross-section longitudinally, exposing the core of both leads, the attachments, slugs, and dies. Photograph the overall parts, the overall die(s), and any anomalies, such as cracks, voids, poor braze wetting, etc. Use a junction etch to bring out the junction structure of the die and rephoto. Use higher magnification and photograph the detail of the junctions in a typical die.

7--Prepare 1 of the 2 mounted diodes for SEM examination by evaporating a carbon coating on the mount. In the SEM, photograph the overall part, the die(s) overall, and every type of interface (typical) in the part: lead-slug; slug-die; die-die; slug-body; etc. Acquire EDX spectra of all of the pieces and all of the phases found at the interfaces, lettering them sequentially and appropriately marking the photos. Because dimensions are foreshortened when mounts are tilted in the SEM, orient the part so that the leads are to the left and right sides, leaving the critical die-slug-lead interface dimensions unaffected. If there is a plating layer, on the leads for example, which should be measure, the part will have to be rotated 90°. However, it should be noted that the correct method to expose and measure such layers is a transverse section (5 above). In the longitudinal section, one has not necessarily intersected the center line and radial thicknesses may not be accurate.

1.5.1.2 Destructive Physical Analysis

Unit Under Test

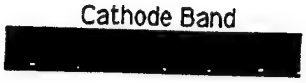
Semtech Diode LSR 9079

Device Markings

Part Number

SFF30

Cathode Band



SFF30
SC

Figure No. A2
Sample No. [illegible]
Magnification: 12x
Comments:
OVERALL OF SAMPLES AS RECEIVED TO SHOW MARKINGS AND EXTERNAL CONDITION. [illegible] SPEED. NOTE PAINT LOSS. SN No.

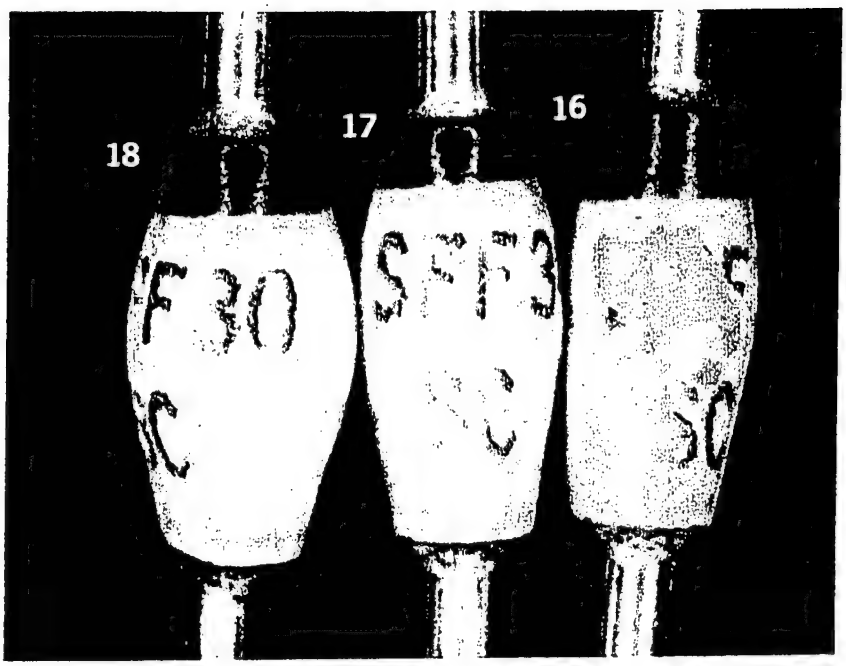
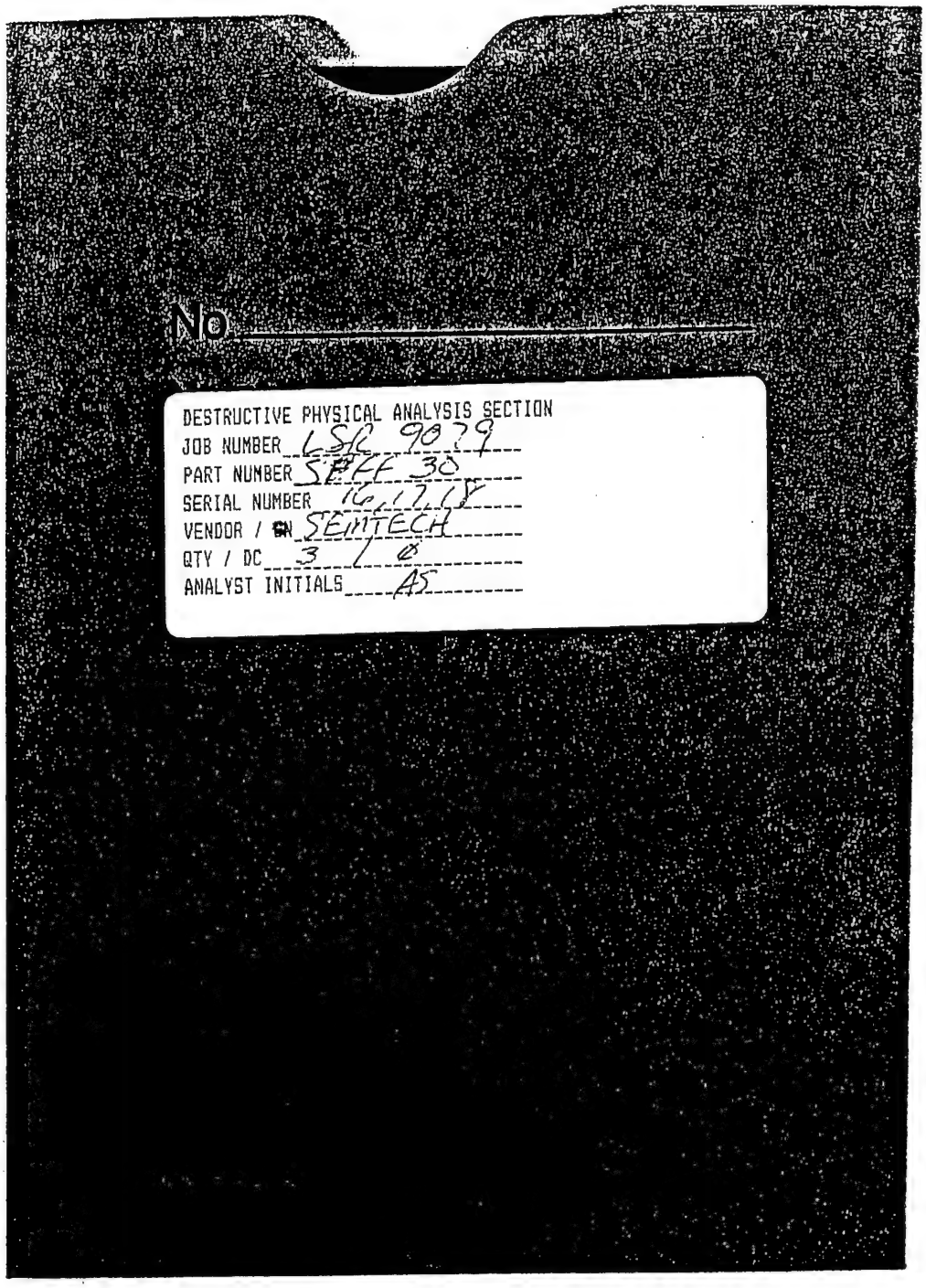


Figure No. 43
Sample No. 16, 17, 18
Magnification: 1x
Comments:

X RAY VIEWS OF
PART Nº SFF30



LEAD PULL TEST
(5 Lb. Max)

PART NUMBER

SFF30

Pass	Fail
✓	

EQUIPMENT USED: Chatillion Pull Tester HAC # NA06575

CALIBRATION DUE: 8-7-91

TECHNICIAN: A. Sierra

DATE: 6-25-91

Figure No. A 4
Sample No. B
Magnification: 10x
Comments:
CLOSE-UP TO SHOW
SOL. WETTABILITY
AND SOLDER
COVERAGE AFTER
SOLDER DIP.

MIL. STD 883

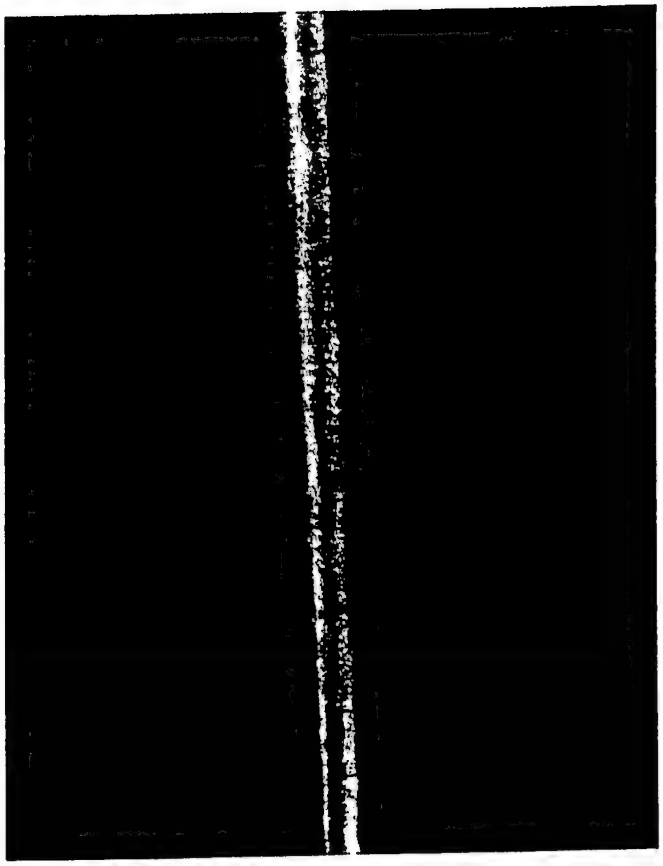


Figure No. A5
Sample No. 17
Magnification: 100X
Comments:
OVERALL OF
CROSS-SECTIONED,
ETCHED LEAD.
SFF30

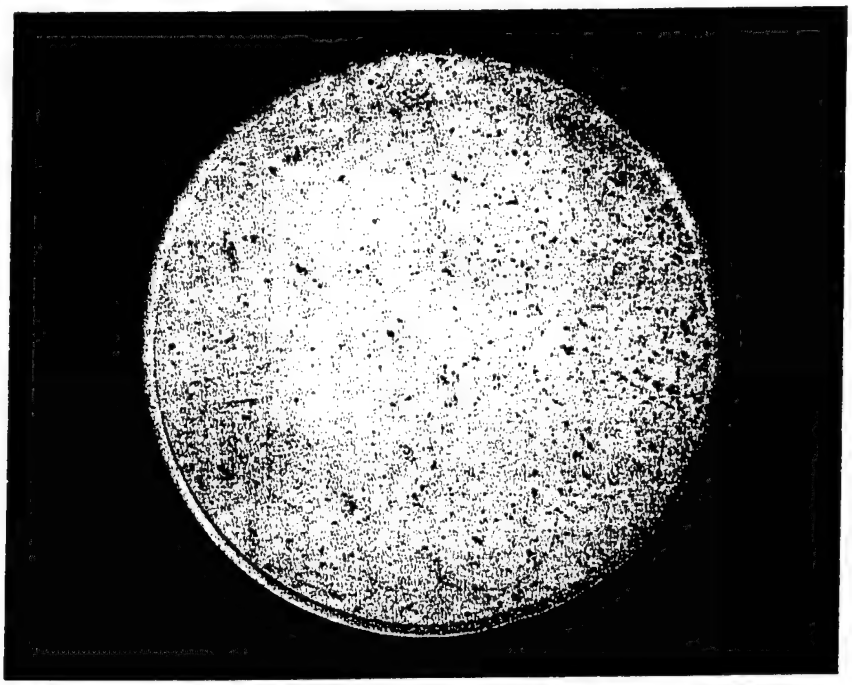


Figure No. A 6
Sample No. 17
Magnification: 1000X
Comments:
CLOSE-UP OF
1) SILVER
2) Ni PLATING.

Figure No. A-7
Sample No. 16
Magnification: 16x
Comments:
OVERALL OF
ETCHED DIODE
CROSS-SECTIONED
MIDWAY.
P/N SFF30.

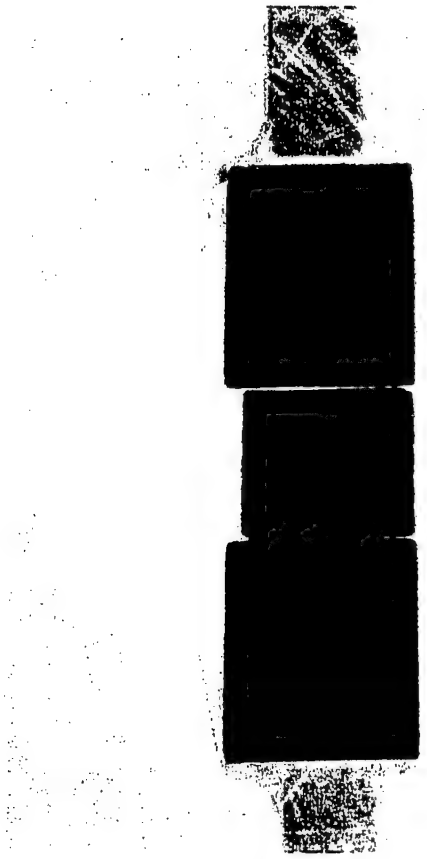


Figure No. A8
Sample No. 16
Magnification: 65x
Comments:
CLOSE-UP OF DIE STACK.

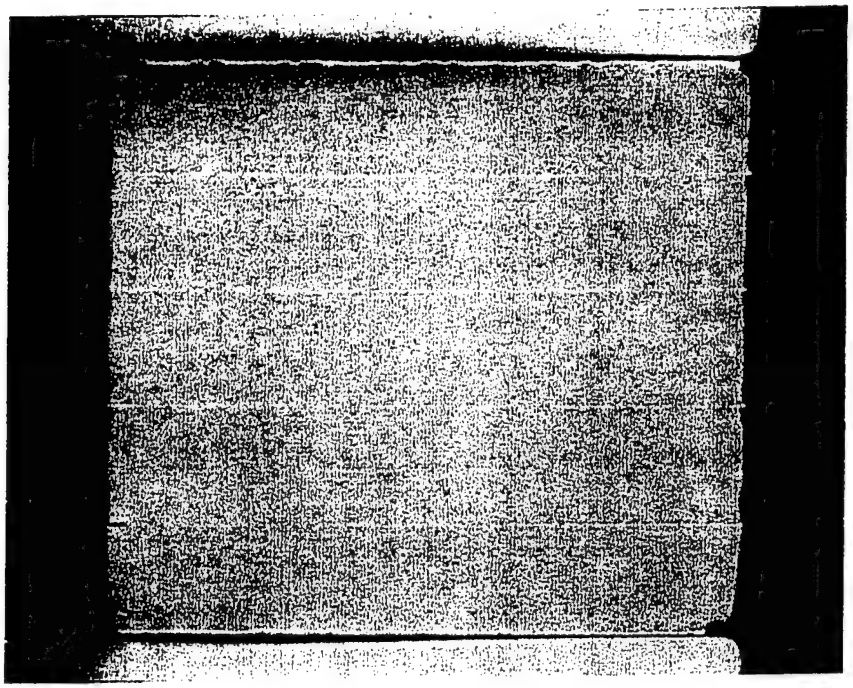


Figure No. A 9
Sample No. 16
Magnification: 65x
Comments:
CLOSE-UP OF ETCHED DIE STACK. ARROWS DENOTE JUNCTIONS.

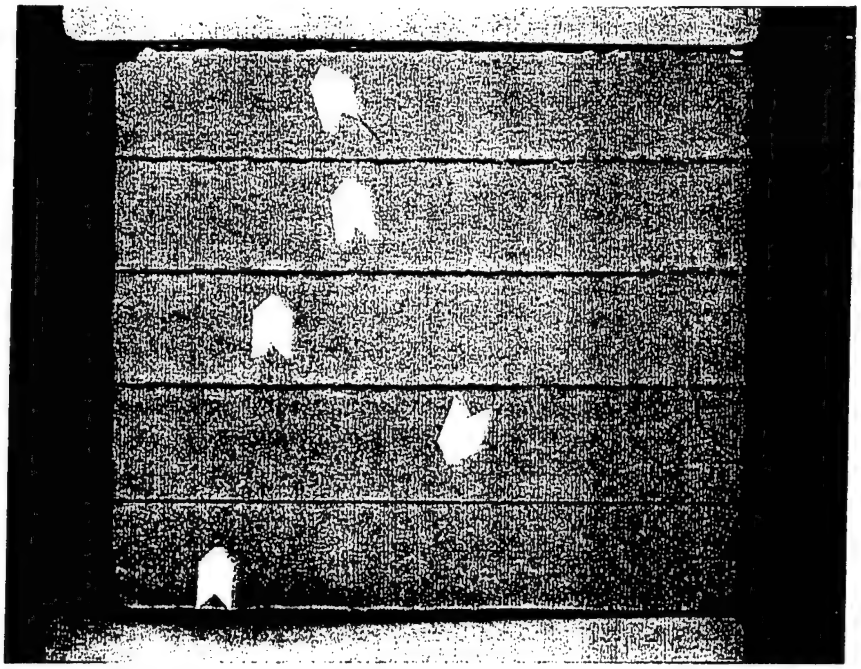


Figure No. A 10
Sample No. 16
Magnification: 65X
Comments:
CLOSE-UP OF DIE ETCHED FURTHER TO REVEAL DIE JUNCTIONS.

NO JUNCTIONS IN LOWEST DIE.

Figure No. A 11
Sample No. 16
Magnification: 200X
Comments:
CLOSE-UP OF DIE ATTACHES AND JUNCTIONS (arrows)

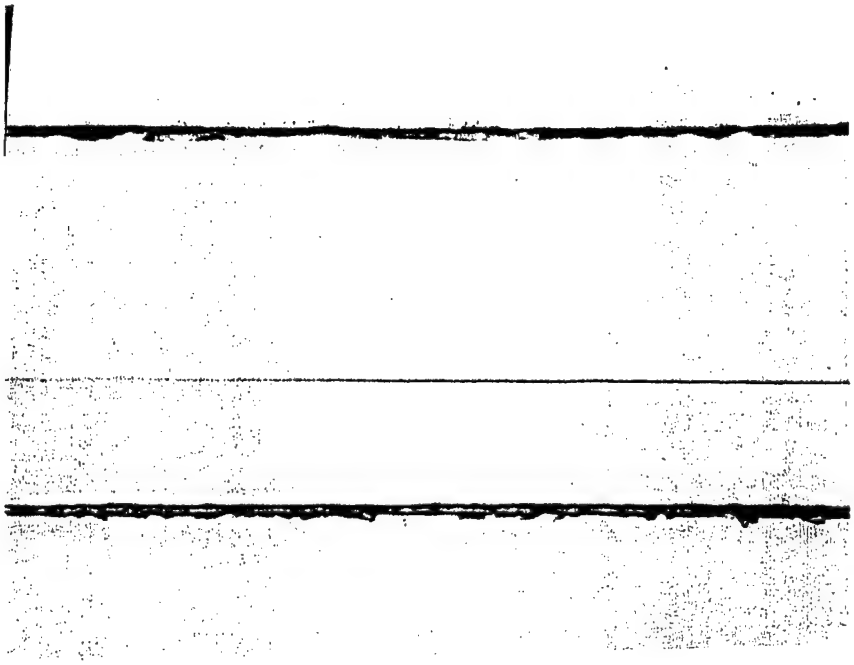


Figure No. A-12
Sample No. 16
Magnification: 1000x
Comments:
CLOSE-UP OF
DIE ATTACH

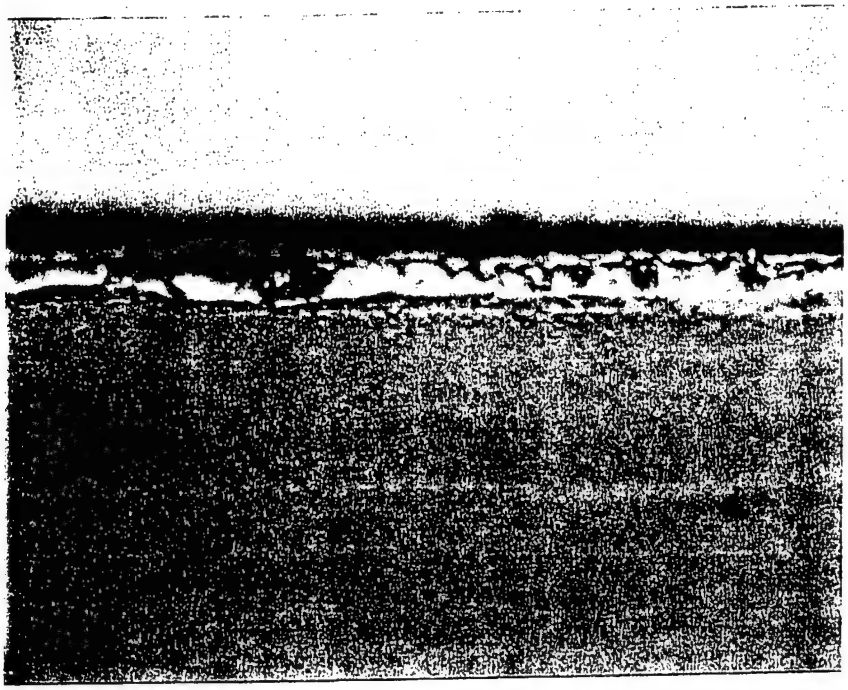
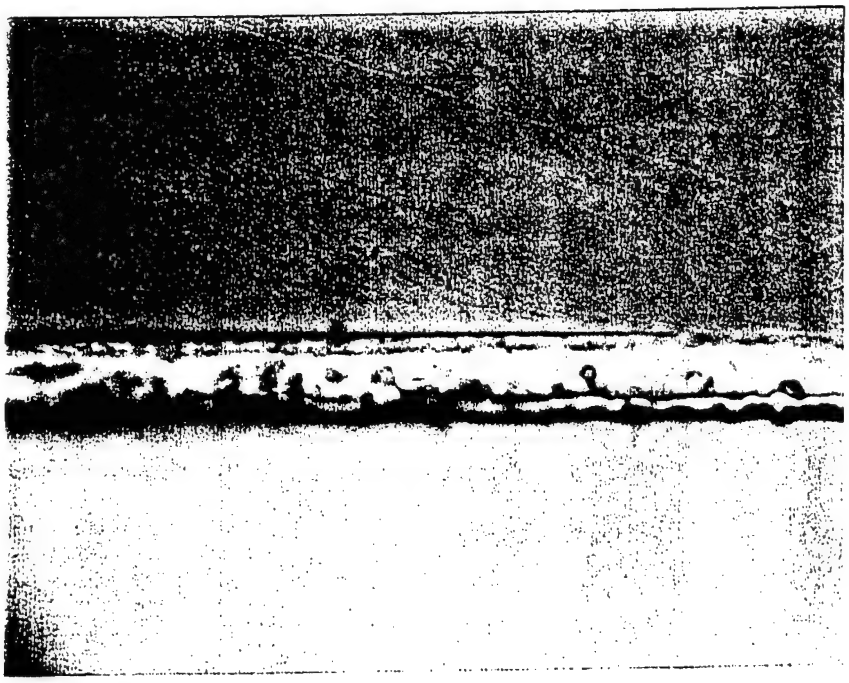


Figure No. A-13
Sample No. 16
Magnification: 1000x
Comments:
OTHER SIDE



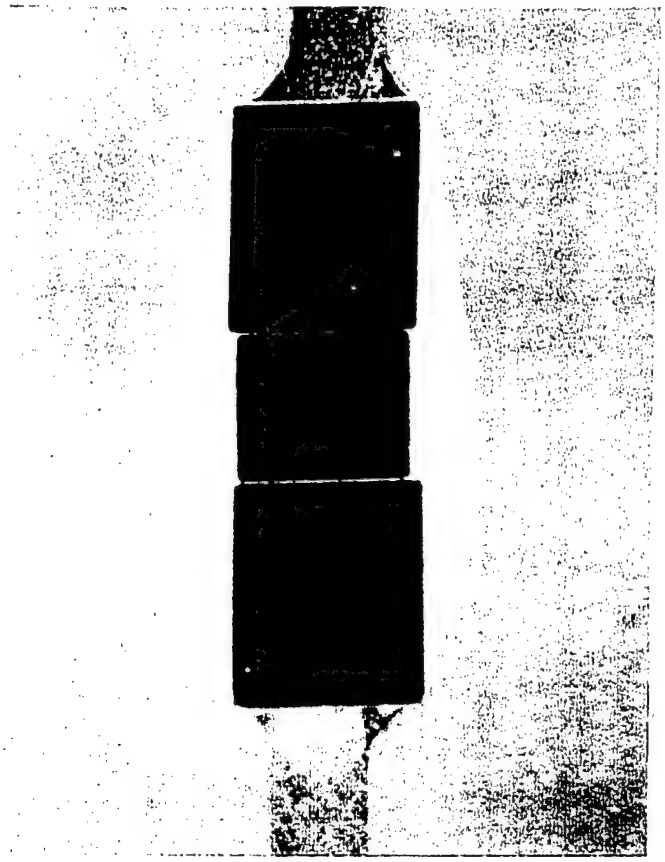


Figure No. A14
Sample No. 17
Magnification: 16x
Comments:
OVERALL OF
ETCHED DIODE
CROSS-SECTIONED
MIDWAY
P/N SF3C.

Figure No. A15
Sample No. 17
Magnification: 63X
Comments:
CLOSE-UP OF DIE STACK. ARROWS DENOTE CRACKS IN DIE AND CASE

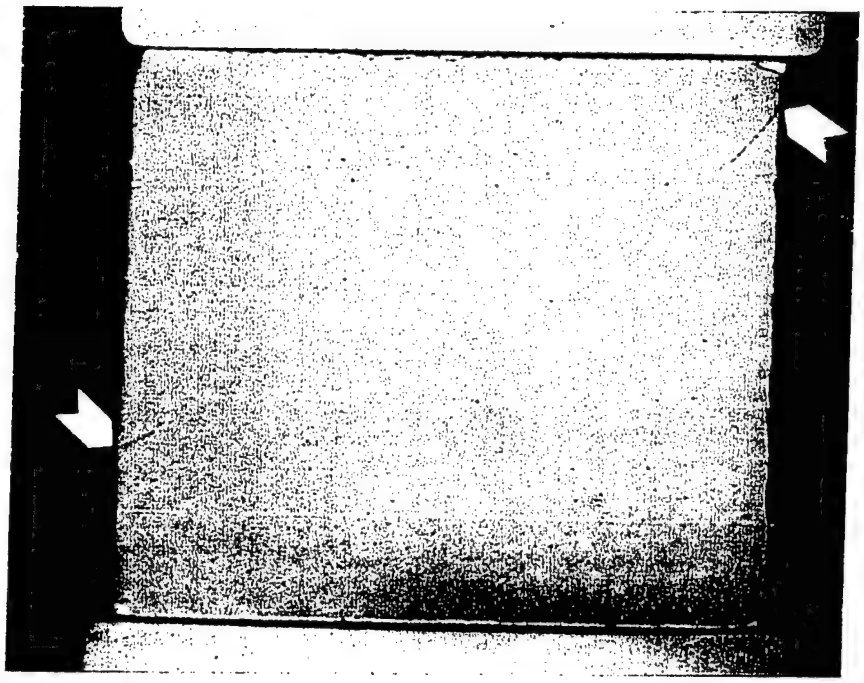


Figure No. A16
Sample No. 17
Magnification: 63X
Comments:
CLOSE-UP OF ETCHED DIE STACK. ARROWS DENOTE JUNCTIONS

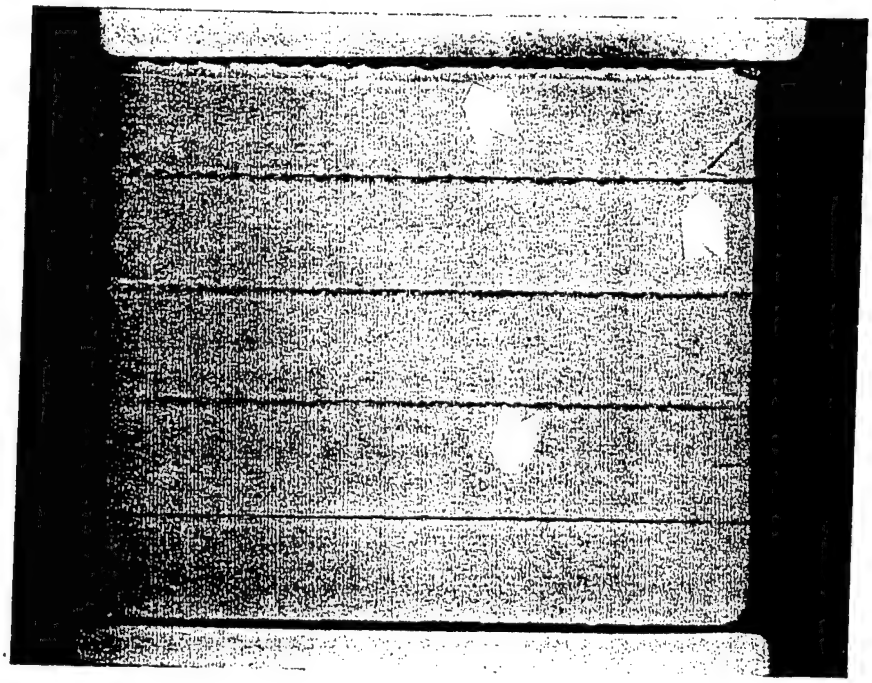


Figure No. A17
Sample No. 17
Magnification: 1000X
Comments:
CLOSE-UP OF
DIE ATTACH.

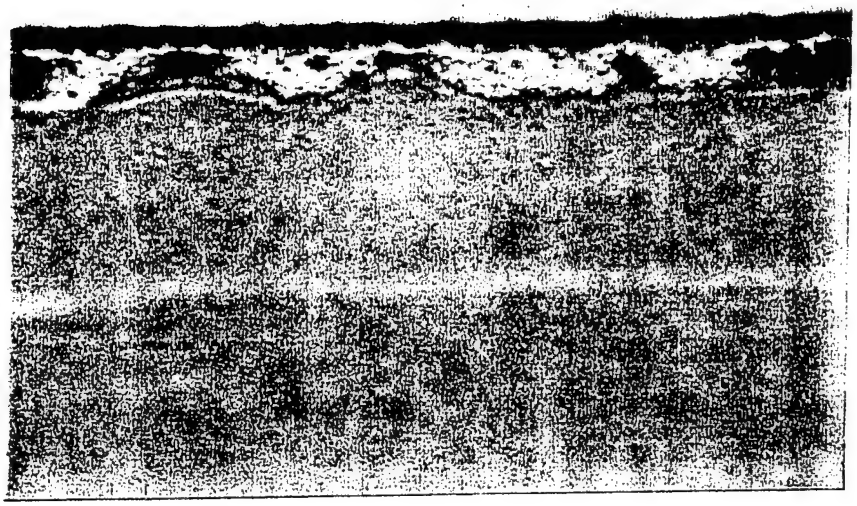


Figure No. A18
Sample No. 17
Magnification: 1000X
Comments:
OTHER SIDE

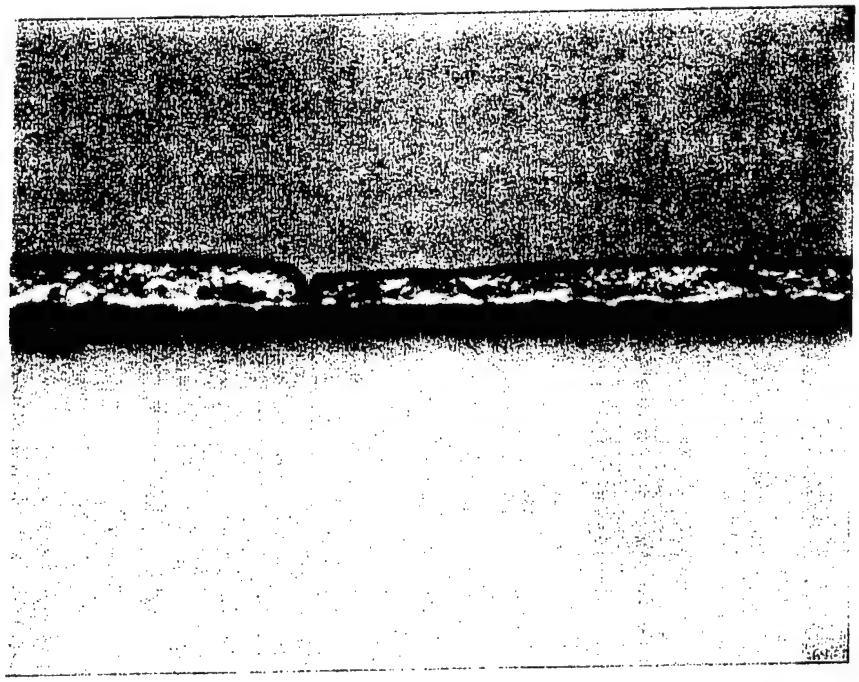


Figure No. A 19
Sample No. 35
Magnification: 15x
Comments:
OVERALL S.E.M. PHOTO.

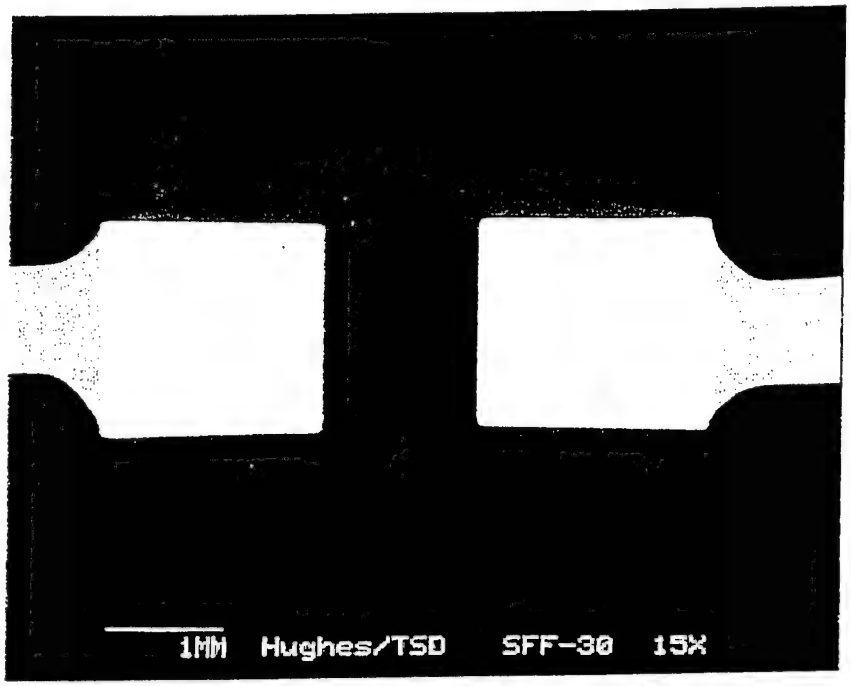


Figure No. A 20
Sample No. 30
Magnification: 70x
Comments:
CLOSE-UP OF DIE STACK.

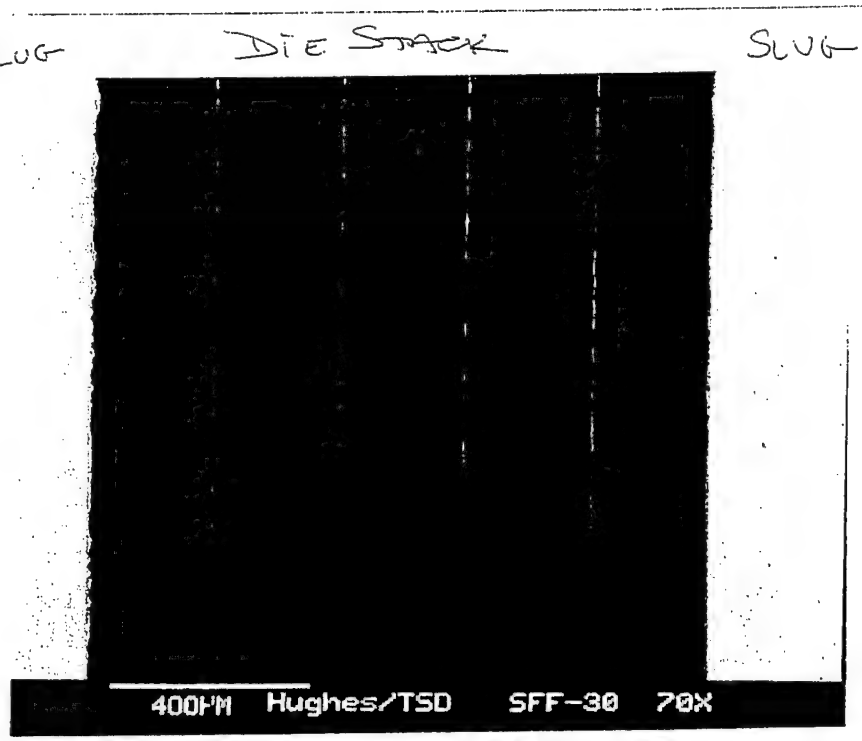
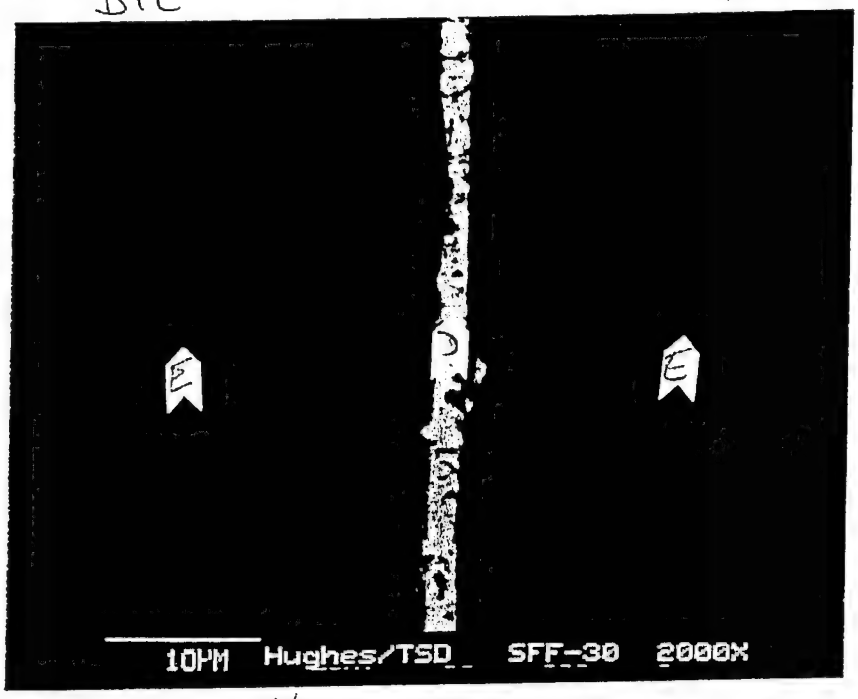
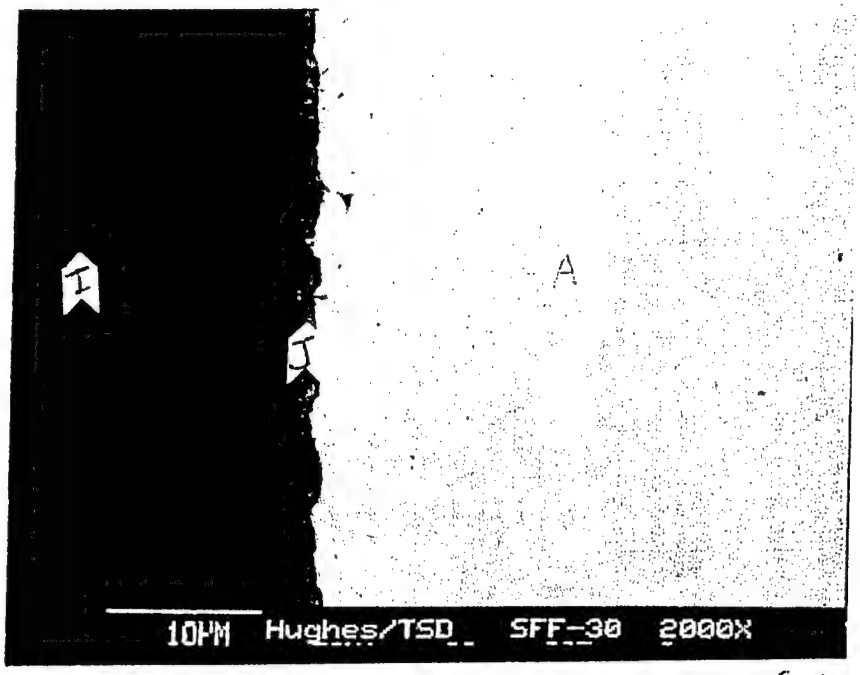


Figure No. A 21
Sample No. 30
Magnification: 2000X
Comments:
CLOSE-UP OF DIE STACK ATTACH.



TYPICAL - 4 PLACES

Figure No. A 22
Sample No. 30
Magnification: 2000X
Comments:
CLOSE-UP OF SLUG (A) AND SLUG PLATING (J) AND CASE (I).



SLUG

Figure No. A 23
Sample No. 30
Magnification: 2000x
Comments:
CLOSE-UP OF
SLUG-TO-DIE
ATTACH

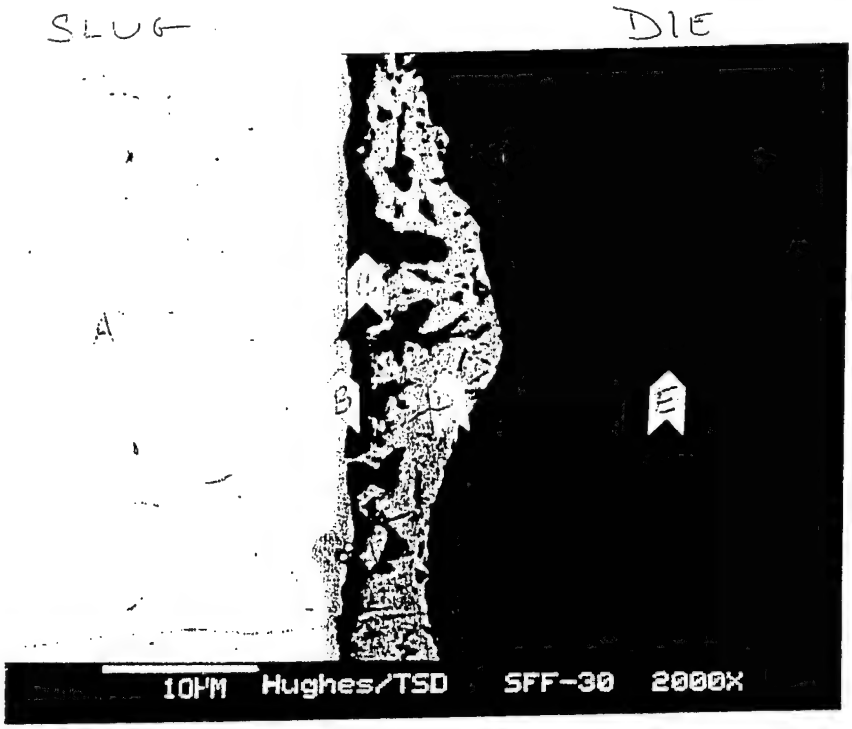


Figure No. A 24
Sample No. 30
Magnification: 2000x
Comments:
CLOSE-UP OF
SLUG-TO-DIE
ATTACH, OTHER
SIDE.

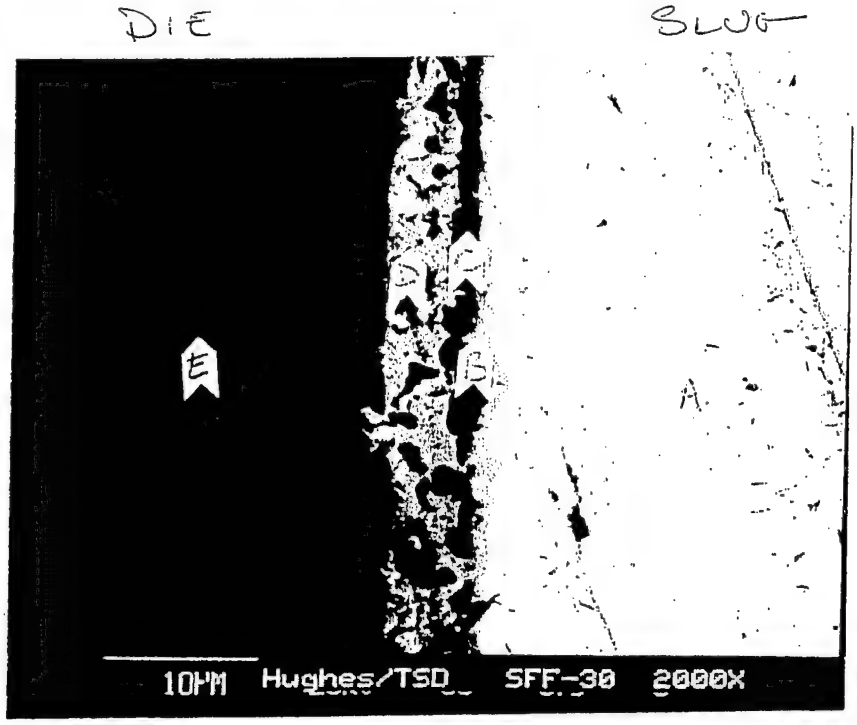
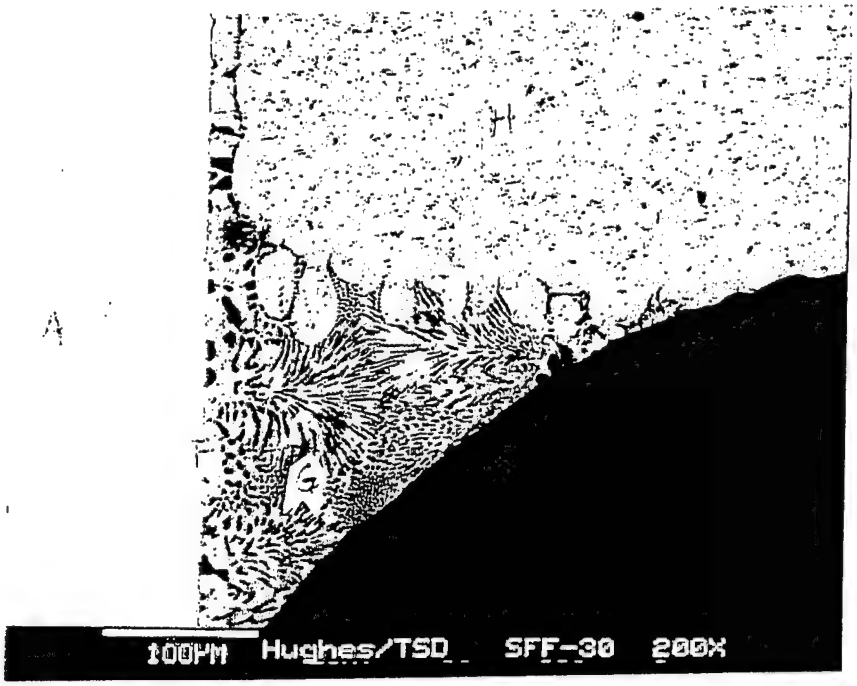


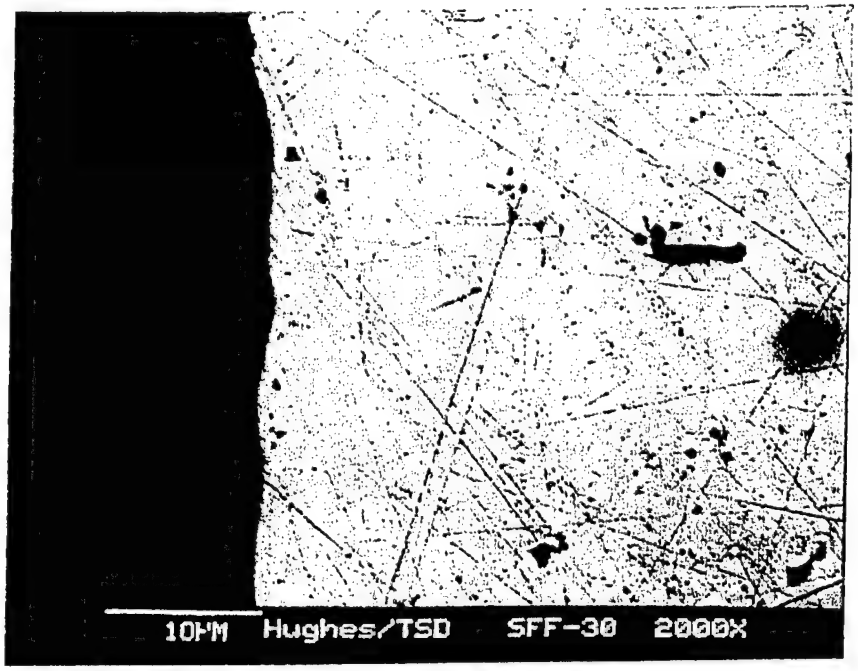
Figure No. A-25
Sample No. 30
Magnification: 200X
Comments:
CLOSE-UP OF SLUG-TO-LEAD ATTACH WITH SOLDER FILLET.

A14



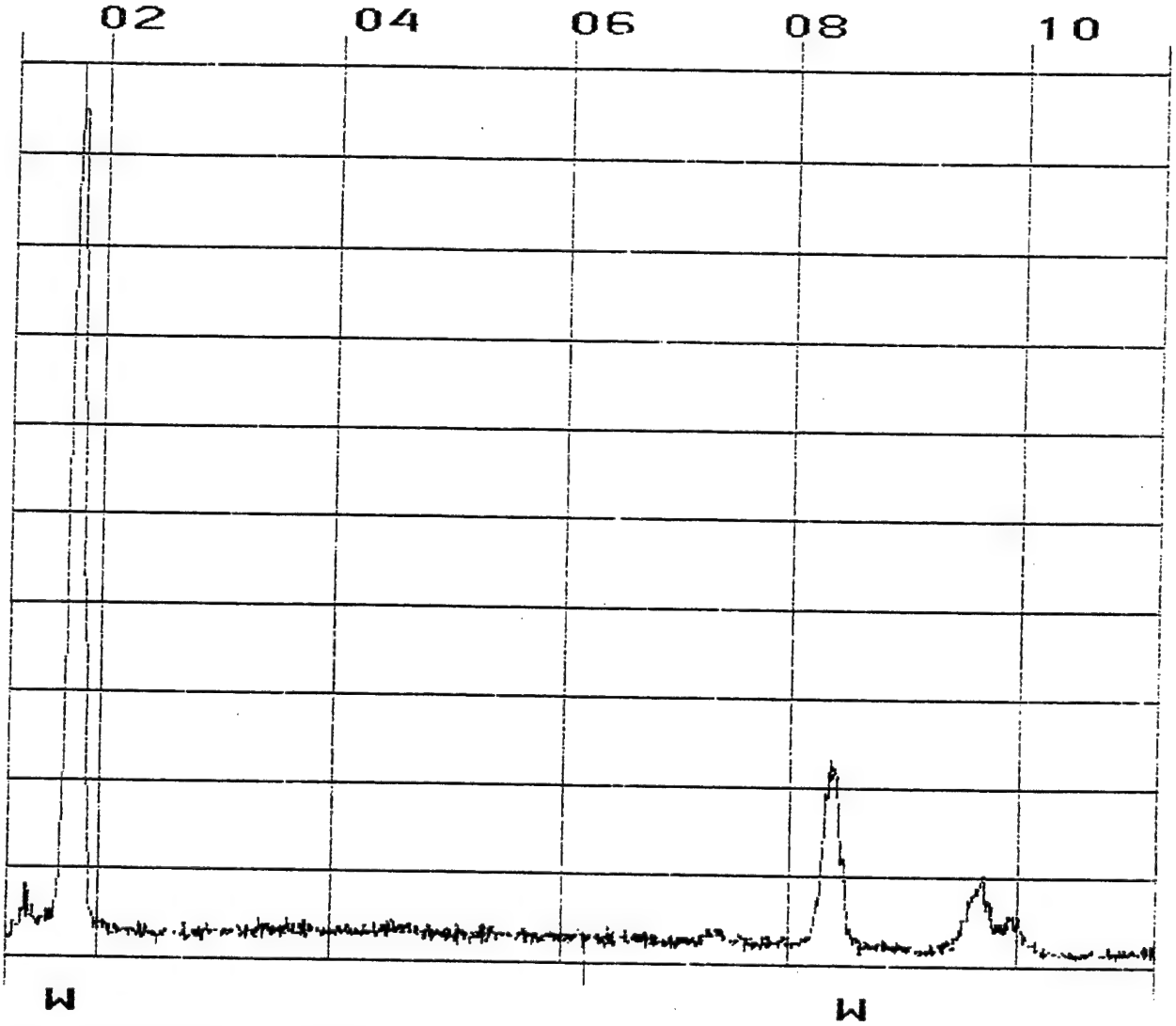
LOAD ATTACH

Figure No. A-26
Sample No. 30
Magnification: 2000X
Comments:
CLOSE-UP OF LEAD.



LEAD

25-JUL-91 08:07:51
RATE: CPS TIME 28LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1020 MEM: A FS= 200

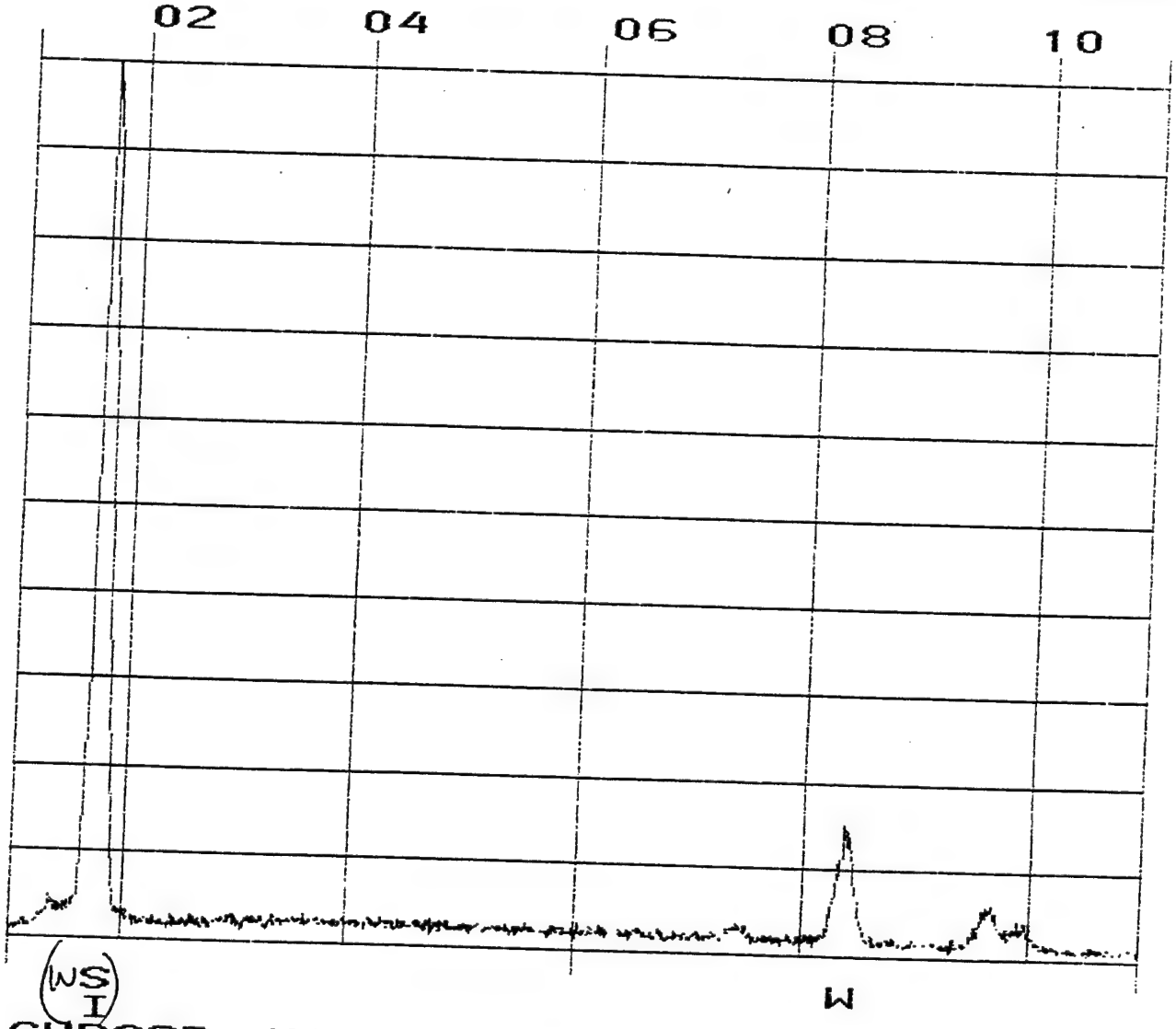


CURSOR (KEV)=06.200 EDAX

SFF-30: AREA A
20KX 20KV HUGHES/TSD

FIG. A27

25-JUL-91 08:10:10
RATE: CPS TIME 38LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1476 MEM: A FS= 200

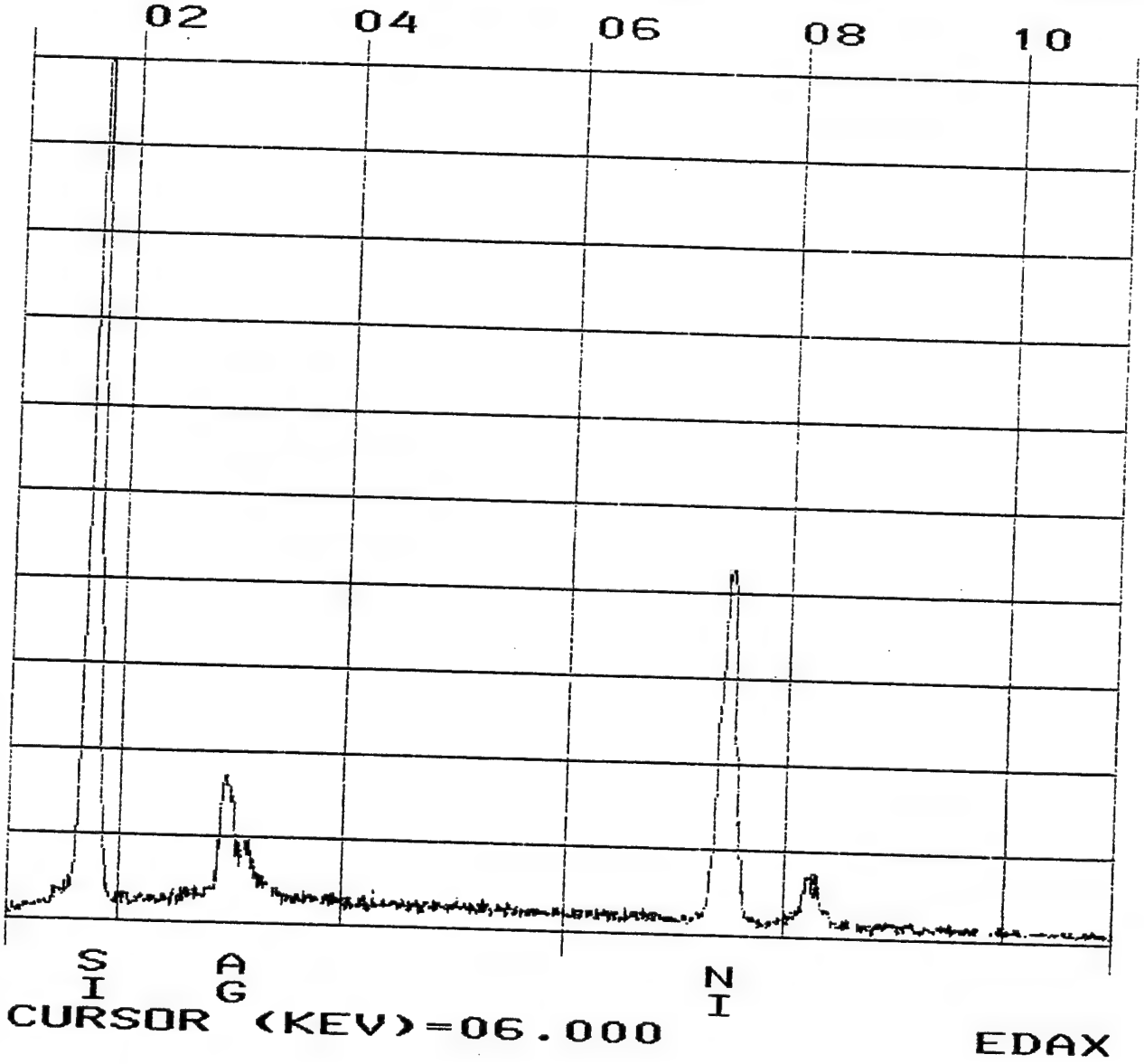


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA B
100KX 20KV HUGHES/TSD

FIG. A28

25-JUL-91 08:12:11
RATE: CPS TIME 44LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1068 MEM: A FS= 200

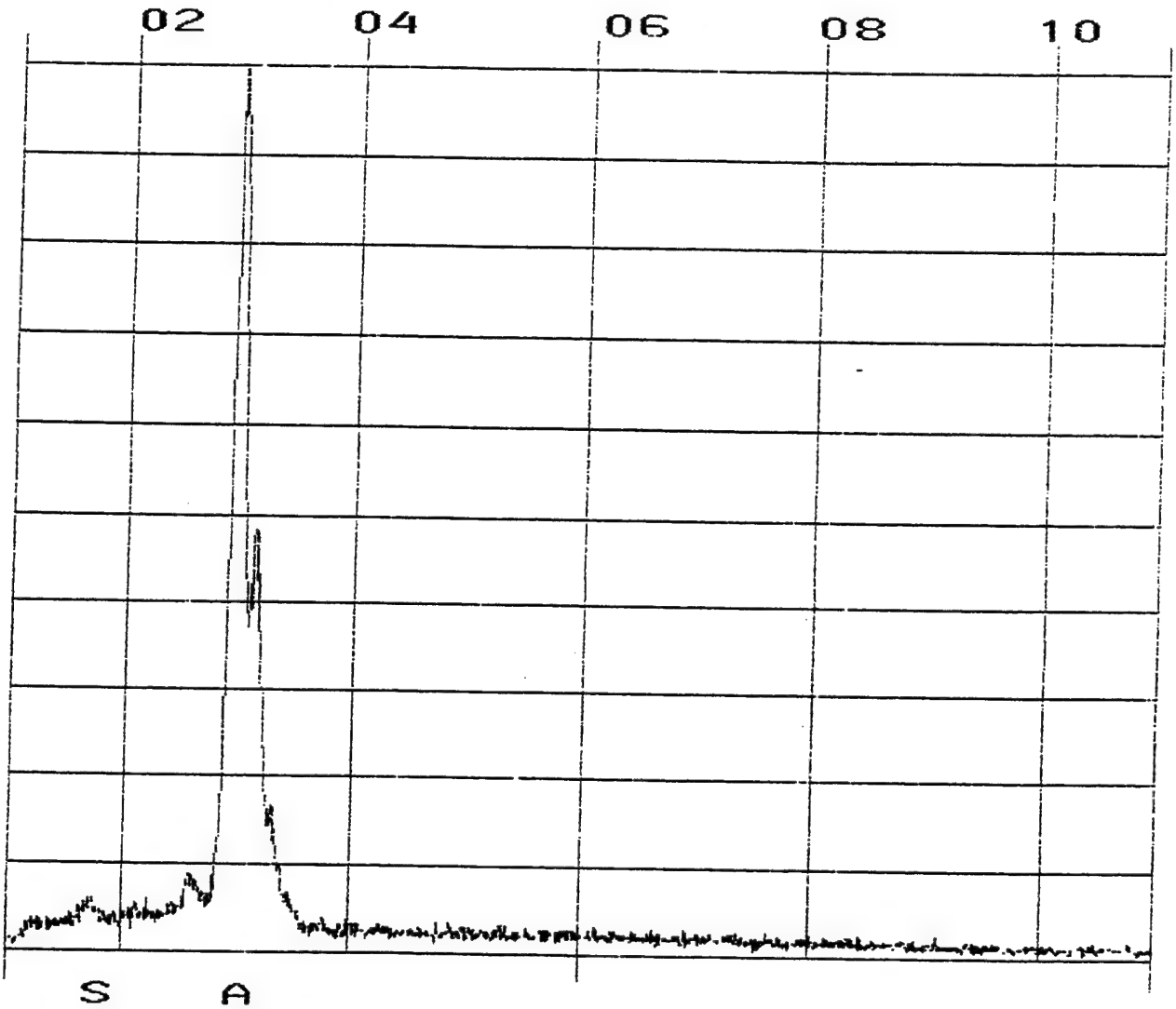


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA C
100KX 20KV HUGHES/TSD

FIG. A29

25-JUL-91 08:14:33
RATE: CPS TIME 0LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1046 MEM: A FS= 200

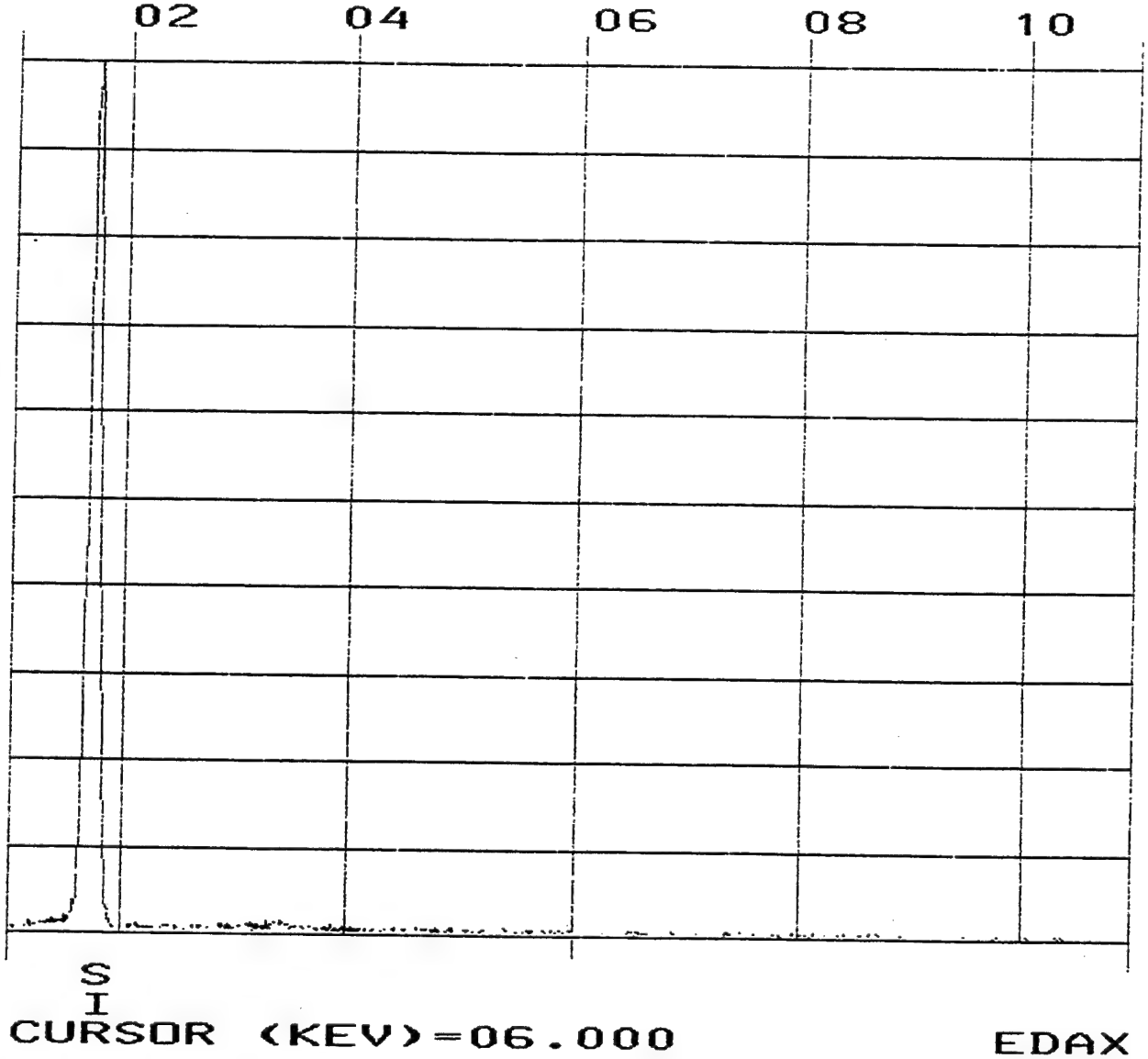


S A
I G
CURSOR (KEV)=06.000 EDAX

SFF-30: AREA D
100KX 20KV HUGHES/TSD

FIG. A30

25-JUL-91 08:16:54
RATE: CPS TIME 17LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1729 MEM: A FS= 200

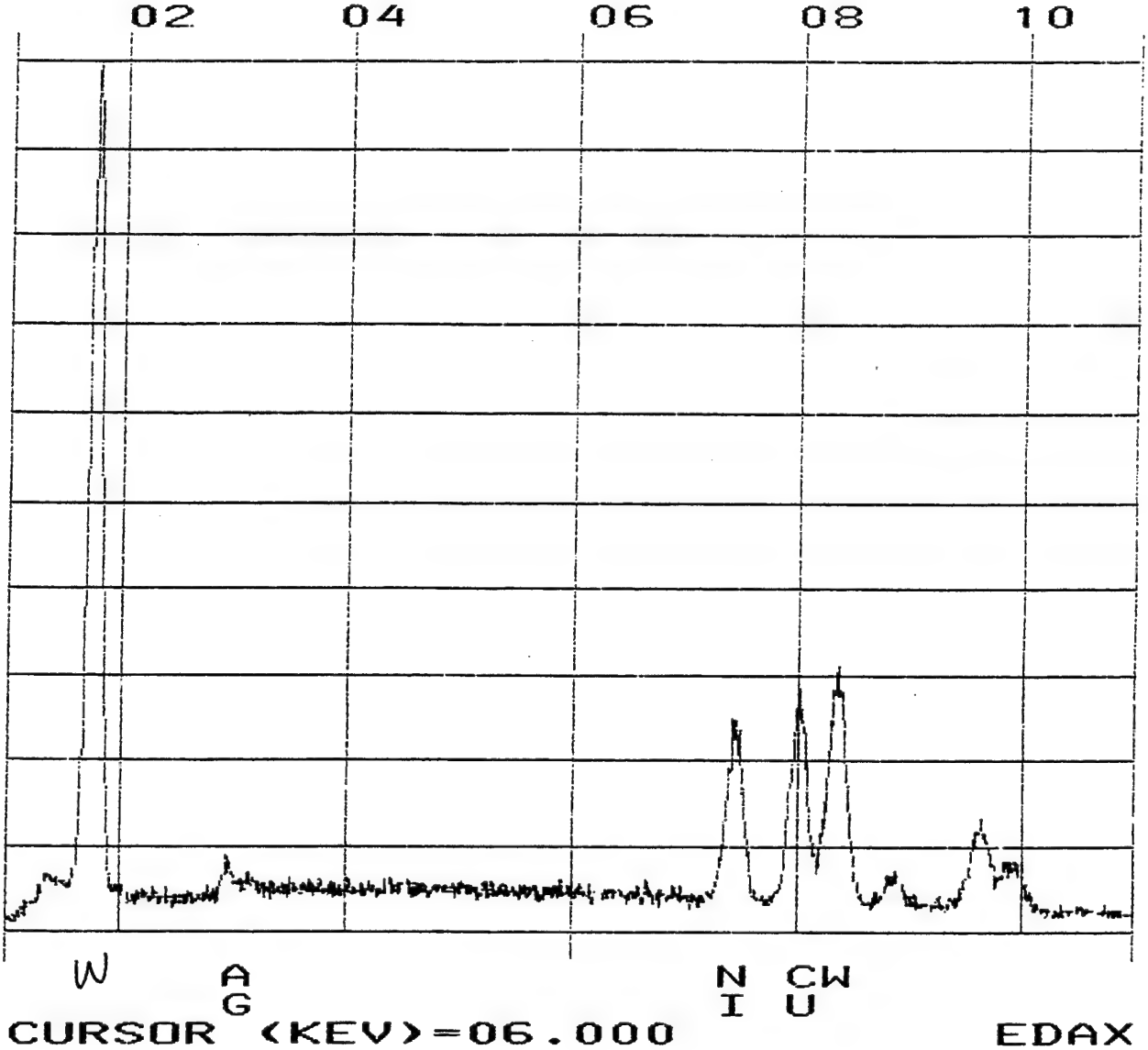


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA E
20KX 20KV HUGHES/TSD

FIG. A31

25-JUL-91 08:19:15
RATE: CPS TIME 75LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1451 MEM: A FS= 200

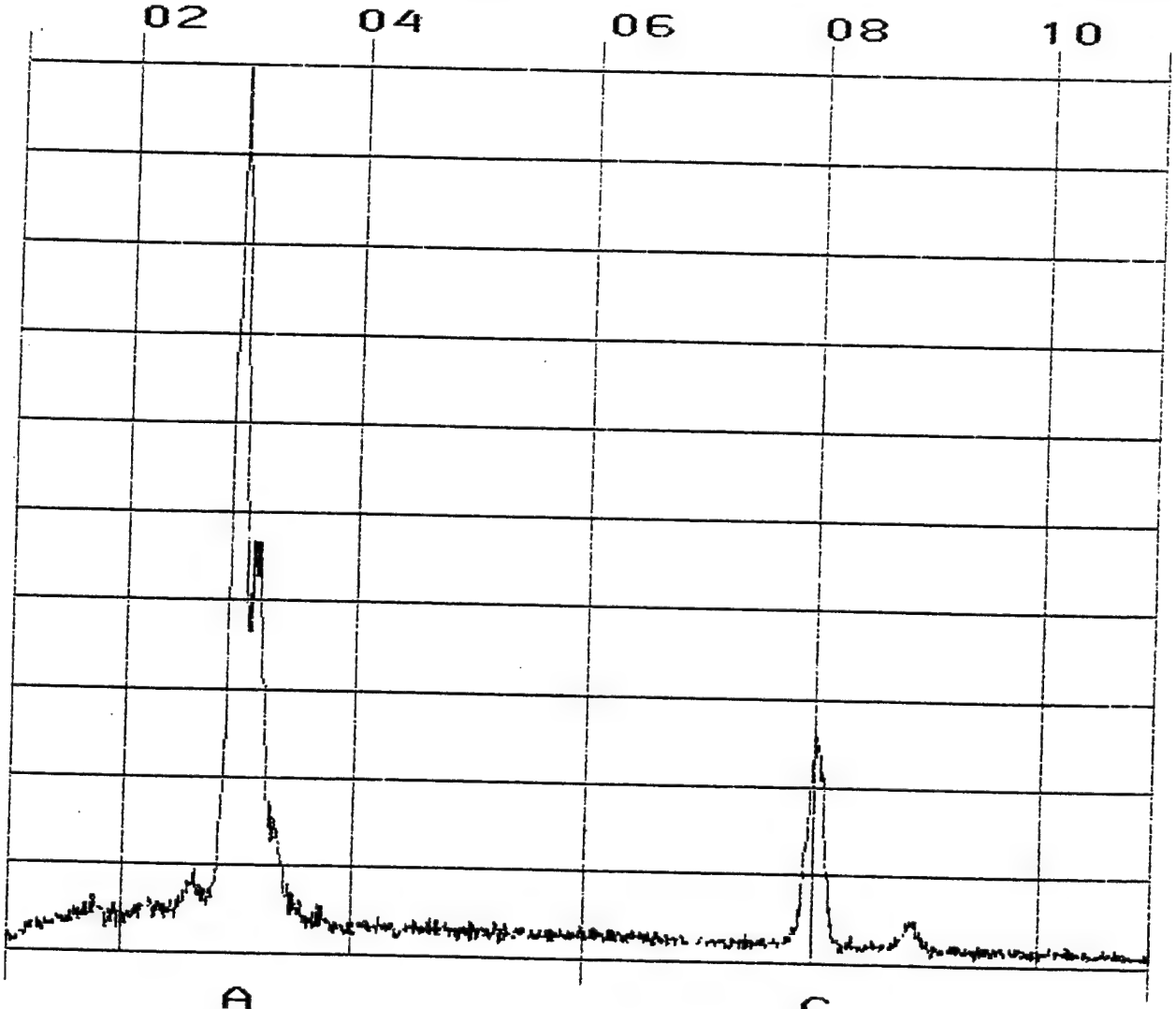


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA F
100KX 20KV HUGHES/TSD

FIG. A32

25-JUL-91 08:21:29
RATE: CPS TIME 33LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1031 MEM: A FS= 200

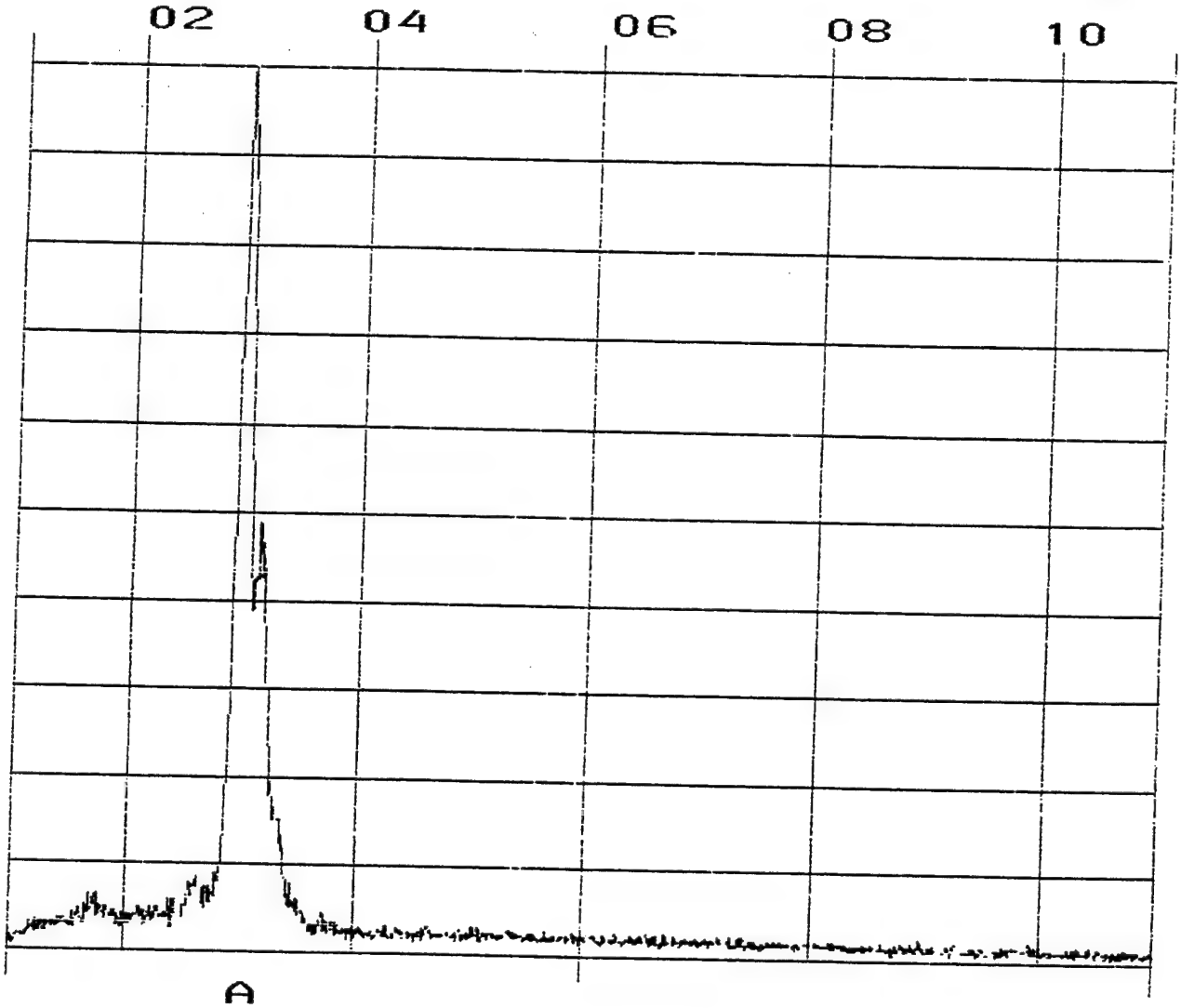


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA G
20KX 20KV HUGHES/TSD

FIG. A33

25-JUL-91 08:23:38
RATE: CPS TIME 24LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1030 MEM: A FS= 200

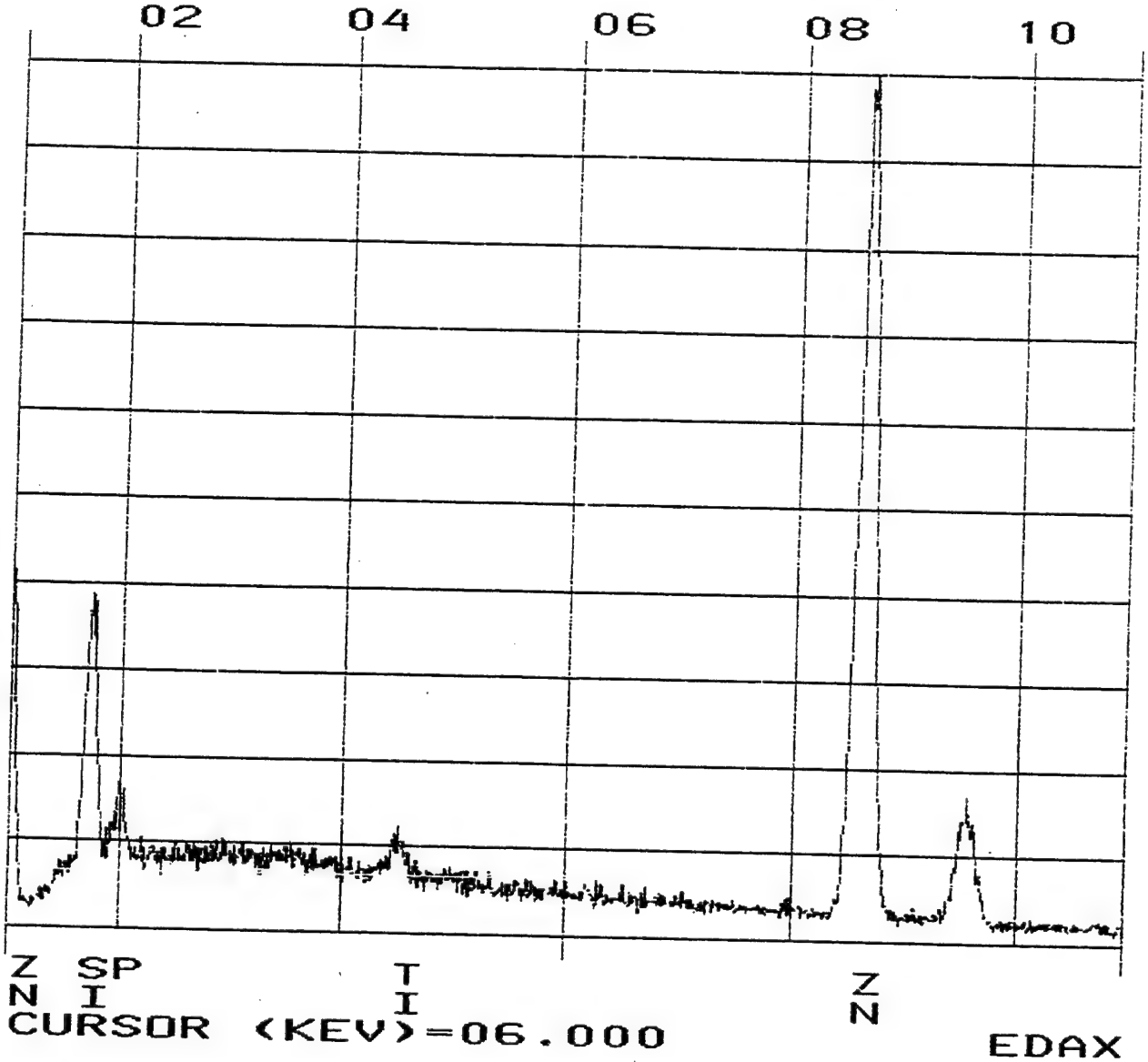


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA H
10KX 20KV HUGHES/TSD

FIG. A34

25-JUL-91 08:26:14
RATE: CPS TIME 116LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1088 MEM: A FS= 200

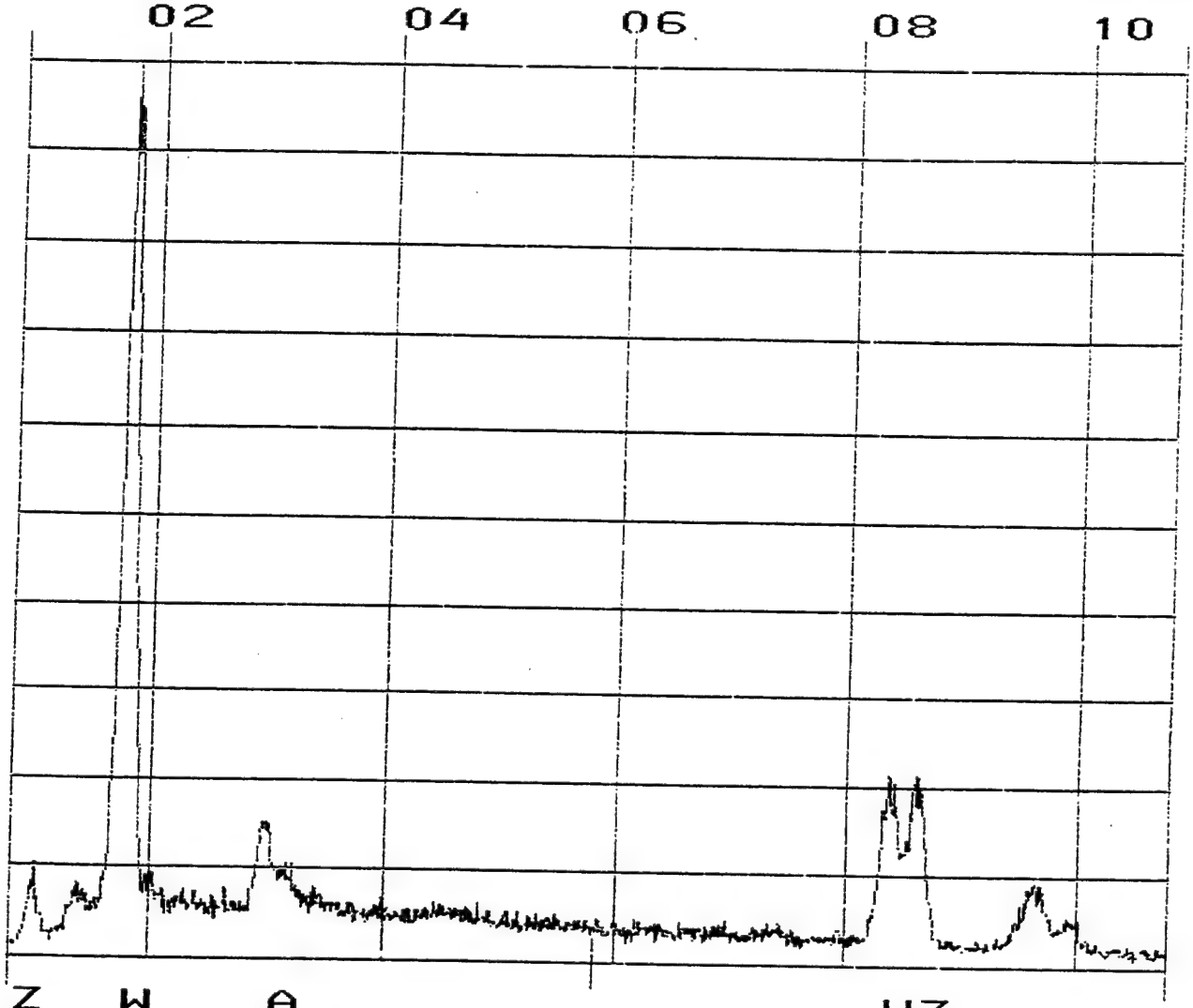


CURSOR (KEV)=06.000 EDAX

SFF-30: AREA I
10KX 20KV HUGHES/TSD

FIG. A35

25-JUL-91 08:28:57
RATE: CPS TIME 58LSEC
00-20KEV:10EV/CH PRST: OFF
A: B:
FS= 1223 MEM: A FS= 200



CURSOR (KEV)=05.800 EDAX

SFF-30: AREA J
100KX 20KV HUGHES/TSD

FIG A36

1.5.2 Evaluation Of High Voltage Diodes

The methods used for diode electrical testing are generally better understood by component engineers and HVPS design engineers than are construction reviews. However, it is clear, a priori, which of the many diode parameters are the most important for HVPS rectifier diode candidate selection. Electrical parameters were evaluated that were thought to be of importance in this application. Ten different part types were obtained from several different manufacturers. The parameters chosen for the study were forward voltage, breakdown voltage, leakage current, reverse recovery time, and turn-on time. Of these, the turn-on times for all of the devices studied were gratifyingly short, the temperature extremes did not cause significant degradation of the measured turn-on time, and the diodes that varied widely in other parameters did not vary appreciably in their turn-on times. Therefore, it appears that turn-on time is not a parameter that needs to be measured for HV diode selection. However, appreciable part-to-part differences were found when testing the diodes for the other four parameters. Furthermore, it appears that the nature of these differences is such that they are significant for part selection. Therefore, it is highly recommended that HVPS manufacturers test diode lots for these four parameters.

Special attention should be paid to the methods by which reverse recovery time is tested. There is not general agreement on a single test procedure for this property; therefore, two methods were used in the testing. As you will see in the following evaluation, one set of test conditions resulted in a significantly larger temperature dependence of the measured reverse recovery time than did the other. This points out the need to test for reverse recovery time under more than one set of experimental conditions.

Understanding the mechanisms by which heat is removed from HV rectifier diodes is important if accurate predictions of diode operating temperatures are to be made. It has generally been assumed that most of the heat generated by diodes potted in solid-encapsulated HVPSs leaves the diodes by conduction through the diode leads; however, it is necessary to understand the contribution of conduction through the diode case and surrounding encapsulant to heat loss. For this purpose MTSs were constructed using strings of three diodes that were instrumented with thermocouples and encapsulated in polymeric materials. Both glass-bodied diodes and plastic-bodied diodes, each dissipating 500 mW in the forward mode. were studied. Details of the MTS design and results ostained are included in Volume 4. However, the results of these studies suggest that lead conduction and case conduction dissipate approximately equal amounts of heat. As a consequence of these studies, it has been concluded that effective heat-sinking of diode strings in HVPS designs should be considered a priority in HVPS design.

1.0 INTRODUCTION

High voltage diodes are to be selected and evaluated for use in a rectifier bridge for a high voltage power supply. This report is a summary of the results of tests on several candidate diodes.

Previously, an initial study was performed to identify the appropriate electrical parameters that should be measured for these devices. Also, the test methods and test conditions for measuring these parameters were developed and then were demonstrated by testing a small population of devices. The results of this initial study were used to establish procedures and guidelines for testing a larger group of candidate devices in this present study. (The results of the initial study were reported in IDC 7641.20/2126 "High Voltage Diode Evaluation" dated 6 December 1991. The IDC was by J.J. Erickson to R.J. Holbrook.)

The initial study resulted in the following recommendations:

(1) Include tests to verify vendor's specified parameters under vendor's test conditions, as well as measuring parameters under probable use conditions (as was done in the initial evaluation).

(2) Include measurements of reverse recovery time under more than one set of test conditions to detect possible variations in temperature dependence.

(3) Omit tests of turn on time unless the vendor's specification warns of excessively long values. This is not a significant parameter for this application.

(4) Repeat the tests that were performed in the initial evaluation unless otherwise noted.

These recommendations were applied to the tests in this study. The first recommendation (regarding testing per vendor's test conditions) was followed to some extent, but it was impractical to test to all of the test conditions of every vendor's specifications. This was especially true for measuring reverse recovery times where the test setup must be optimized for each set of test conditions.

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Some additional tests were also included as a result of recommendations made by the program's technical monitors. Specifically, reverse recovery times were measured at an additional temperature (85°C) in order to better understand the variation of these switching times with temperature.

2.0 TEST SAMPLES AND MEASUREMENTS PERFORMED

Several types of diodes made by various vendors were evaluated. Table 1 is a summary of the diode types, their vendors and the vendors' rated values of their parameters. Table 2 summarizes the various electrical parameters that were measured for each diode and the test conditions for each diode parameter. In general, the test conditions were based on the requirements of the power supply in which the diodes are to be used plus some additional tests to verify the devices' conformance to the vendor's specification. The diodes' parameters were measured at three temperatures: room ambient (25°C), -55°C and 125°C. The electrical parameters that were measured included V(f), the forward voltage drop, at three currents; BV, the reverse breakdown voltage; I(L), the reverse leakage current; and t(rr), the reverse recovery time, under two conditions (at an additional temperature of 85°C). Figure 1 shows waveforms for the test conditions used to measure the devices' reverse recovery times. Table 3 is a summary of the serial numbers assigned to the various device types.

3.0 RESULTS

3.1 SUMMARY OF FORWARD VOLTAGE MEASUREMENTS:

Table 4 is a summary of all V(f) measurements on all devices at all temperatures. Included in the table are the average values of V(f) for each device type for each test condition and temperature.

The values of V(f) for each diode in each group were plotted on graphs. Figure V1 is the first of these graphs. The X-axis of the graph shows the serial number of each device in the group. The Y-axis is the magnitude of V(f). Values of V(f) for a particular test condition (i.e. a specific current and temperature) were connected to generate a profile for that particular group of devices.

This is not a typical approach for data presentation since the value of V(f) for each device is not related to the value of V(f) for other devices. However, the profile that is generated for each group of devices under a specific test condition can be easily compared to a profile for another condition to see if the behavior of the group of devices is consistent from condition to condition.

The resulting profiles also provide an indication of the uniformity of the measured parameter, here V(f), for the population under evaluation. Such profiles

can serve as a measure of both uniformity and quality for a device type and product lot.

The following table summarizes the device types, test conditions and the figure number which corresponds to a plot of the test results for the various V(f) measurements.

Summary of Figures Illustrating V(f) Values

Device Type	Measurement Current (mA)	Figure Number
PFFO	10	V1
	100	V2
	250	V3
PFF6	10	V4
	100	V5
	250	V6
SFF30	10	V7
	100	V8
	250	V9
MUR1100E	10	V10
	100	V11
	250	V12
MUR160	10	V13
	100	V14
	250	V15
1N6515	10	V16
	100	V17
	250	V18
SRS1100HE	10	V19
	100	V20
	250	V21
BYV26E	10	V22
	100	V23
	250	V24
BYV26C	10	V25
	100	V26
	250	V27
SDR1M	10	V28
	100	V29
	250	V30
1N6615	10	V31
	100	V32
	250	V33

The V(f) measurements on all devices were, in general, fairly consistent within each device type for all current values at 25 and 125°C. However, the V(f) values at -55°C show a large variation even within each device type. Device type SFF30 was the exception to the preceding general statement. This device type exhibited large variations in forward voltage from device to device even at room temperature.

Average values of V(f) for each set of test conditions within each part type were generated. These average values were used to compare part type to part type. Figure V34 shows a plot of the average V(f) at 10 mA of current for part types PFF0, PFF6, MUR1100E and MUR160 for the three temperatures. Figures V35 and V36 are similar plots for currents of 100 and 250 mA.

Figures V37, V38 and V39 combine the forward voltages of device types SRS1100, BYV26E, BYV26C and SDR1M for currents of 10, 100 and 250 mA respectively.

Figure V40 shows the forward voltage drops of device types SFF30 and 1N6515 for all currents. These device types were plotted together since they had much larger forward voltage drops than the other device types.

Figure V41 shows the devices plotted in Figure V40 along with two of the other device types with the lower forward voltage drops, types PFF6 and BYV26E. Of the devices with relatively low forward voltage drops these device types had the lowest and highest values of forward voltage.

Figures V42, V43 and V44 are summary charts showing the average forward voltage values for all device types for 10, 100 and 250 mA, respectively. The variation of forward voltage with the three temperatures is also shown on these charts.

3.2 SUMMARY OF BREAKDOWN VOLTAGE MEASUREMENTS:

Table 5 includes all breakdown voltage measurements on all devices at all temperatures. The very high voltage breakdown devices were not measured at 125°C to avoid possible overstress damage. Some other values of breakdown voltage were not available in the test data package used for this report. However, sufficient data was available to evaluate the various device types.

Some breakdown values measured at 125°C were found to be not valid. This was due to the fact that the reverse current criteria used for breakdown was exceeded by the leakage current at this high temperature. Therefore, the value that was recorded was too low. There was still sufficient data without these values to evaluate the various device types.

Breakdown voltages for the individual devices in each part type group are shown in Figures as listed in the following table.

Summary of Figures Illustrating Breakdown Voltage Values

Device Type	Figure
PFFO	B1
PFF6	B2
SFF30	B3
MUR1100E	B4
MUR160	B5
1N6515	B6
SRS1100HE	B7
BYV26E	B8
BYV26C	B9
SDR1M	B10
1N6615	B11

All devices met the vendors' breakdown voltage specification at 25°C. The vendors did not specify breakdown voltage requirements for -55 and 125°C.

Some device types exhibited large variations in the breakdown voltage from device to device. For example, device types SFF30, MUR1100E, SRS1100HE and 1N6615 all exhibited ranges of breakdown voltages (from device to device within a device type) greater than 10% of their 25°C nominal values. As expected, breakdown voltages within a given device type varied uniformly from device to device over temperature.

Figure B12 is a graph showing average breakdown voltages for all device types for all three temperatures. Figure B13 shows the same chart with device types 1N6515 and SFF30 removed to show more detail for the lower breakdown voltage types remaining on the chart.

3.3 SUMMARY OF LEAKAGE CURRENT MEASUREMENTS:

Table 5 also includes leakage current measurements on all devices at all temperatures. As in the case of some of the breakdown voltage measurements, some values of leakage current were not available in the test data package used for this report. However, sufficient data was available to evaluate the various device types.

All devices' leakage currents were well under the vendors' specified maximum value at room temperature. The vendors did not specify the leakage current requirements for -55 and 125°C.

The following table summarizes the figures which show leakage current measurements on the devices within each device type.

Summary of Figures Illustrating Leakage Current Values

Device Type	Figure
PFFO	L1
PFF6	L2
SFF30	L3
MUR1100E	L4
MUR160	L5
1N6515	L6
SRS1100HE	L7
BYV26E	L8
BYV26C	L9
SDR1M	L10
1N6615	L11

There was some variation in leakage current from device to device within a specific device type at -55 and 25°C as expected. At 125°C, there is relatively little variation within the devices in a specific device type.

Figure L12 is a summary of all leakage currents for all device types for the three temperatures. It can be seen that there was not a large difference in leakage currents from device type to device type.

3.4 SUMMARY OF REVERSE RECOVERY TIME MEASUREMENTS:

Table 6 includes two reverse recovery time measurements, t(rr)1 and t(rr)2, on all devices at all temperatures (See Table 2 for test conditions for t(rr)1 and t(rr)2). There is some minor variation in t(rr)1 from device to device within a specific device type at 125°C as expected. At -55 and 25°C, there is relatively little variation in t(rr)1 within the devices within a specific device type.

The vendors did not specify reverse recovery time limits for the conditions used to measure t(rr)1 or t(rr)2. Measurement of the reverse recovery times under specific conditions specified by each vendor would have been costly and time consuming since each test condition requires a separate tuned test fixture.

Values for t(rr)1 and t(rr)2 for the individual devices in each part type are shown in figures as listed in the following table.

Summary of Figures Illustrating t(rr)1 and t(rr)2 Values

Device Type	t(rr)1 Figure	t(rr)2 Figure
PFFO	T1	T12
PFF6	T2	T13
SFF30	T3	T14
MUR1100E	T4	T15
MUR160	T5	T16
1N6515	T6	T17
SRS1100HE	T7	T18
BYV26E	T8	T19
BYV26C	T9	T20
SDR1M	T10	T21
1N6615	T11	T22

The results of the measurements of t(rr)1 showed that all device types were fairly consistent from device to device within a device type at -55 and 25°C. Several of the device types exhibited some variations in their values from device to device at 125°C, and a few also exhibited variations at 85°C. The variation with temperature was fairly consistent from device to device except for the 1N6515 devices. These devices did not exhibit consistent variation with temperature.

In the initial study that was previously performed, t(rr)1 and t(rr)2 were measured at only three temperatures (-55, 25 and 125°C). The plots of t(rr) versus temperature indicated the possibility of a discontinuity in the behavior of t(rr) for some of the devices. That is, from 25 to 125°C there was a much larger increase in t(rr) than from -55 to 25°C suggesting that this parameter might have some critical temperature at which it "runs away". It was more probable, however, that the parameter simply increased much more rapidly at higher temperatures.

To resolve this problem, a measurement of t(rr)1 and t(rr)2 was made at an additional temperature of 85°C in this study. Figures T23 to T25 are comparisons of the behaviors of the average t(rr)1 for the device types versus temperature. Figures T26 to T28 are comparisons of t(rr)2. It can be seen that t(rr) is a continuous function that does increase more rapidly at higher temperatures for some device types.

Figure T29 is a summary of t(rr)1 values for all device types for all temperatures. Most of the devices had values of t(rr)1 that were comparable to each other with the 1N6515 devices having the longest time at room temperature. However, the values of t(rr)1 for the 1N6515 devices were much longer at elevated temperatures.

The summary comments for the t(rr)2 values are the same as the comments for the t(rr)1 values. Figure T30 is a summary of all t(rr)2 values for all devices at all temperatures. Again, the 1N6515 devices have much longer times than all of the other devices at elevated temperatures.

4.0 SUMMARY OF DIODE EVALUATION

The results of the testing that was performed on the diodes are summarized by device type. If no comments are made about a parameter for a device type, this indicates that the parameter had an average value compared to other device types.

PFF0: All parameters were found to be average compared to other devices. No specific differences or problems were noted.

PFF6: Forward voltages were low compared to other devices, but this device had the lowest breakdown voltage of all devices. The variation of leakage current with temperature was not consistent from device to device within this type.

SFF30: Forward voltages were very high compared to other devices, but this device had the second highest breakdown voltage. There were large variations in both forward voltage and breakdown voltage from device to device within this type.

MUR1100E: Large variations were noted in the breakdown voltages from device to device within this type. The leakage average leakage current was the highest of all devices measured at room temperature but was not unacceptably high. The reverse recovery times were short compared to the other devices.

MUR160: Forward voltage was low. The variation of leakage current with temperature was inconsistent from device to device. The reverse recovery times were short compared to other types.

1N6515: Forward voltages were high, but this device type exhibited the highest breakdown voltage. The reverse recovery times were the longest of all device types, and increased much more than other types at elevated temperatures. The leakage currents exhibited the largest changes with temperature, but did not get unacceptably high.

SRS1100HE: All parameters were average compared to other devices. There was a large variation of breakdown voltage from device to device within this device type.

BYV26E: All parameters were average compared to other devices. No specific differences or problems were noted.

BYV26C: Reverse recovery times were short for this device type. All other parameters were average compared to other devices

SDR1M: All parameters were average compared to other devices. No specific differences or problems were noted.

1N6615: It was found that this device had a limited reverse current capability as a result of an initial group of devices that were overstressed. The data for the subsequent group of devices that were tested was incomplete at the time of this report. However, it was concluded that sufficient data had been obtained to make a valid comparison to the other device types. If additional data is required, it will be obtained and reported in future reports.

5.0 ADDITIONAL SIGNIFICANT PARAMETER:

During a review of high voltage systems that have been previously designed and built, an additional significant electrical parameter was determined. This parameter is the transient forward voltage of a diode.

When a diode first starts to conduct in the forward direction, the resistance is not immediately low. In many applications, this effect is not noticed since the forward current does not rise rapidly and the amount of voltage available is limited. However, in the case of rapidly switched high voltage power systems this effect becomes significant.

Figure 2 shows a sketch of the current and voltage waveforms associated with transient forward voltage. As the forward current initially rapidly rises, the forward voltage also increases rapidly since the diode's forward resistance has not yet decreased. As the diode's resistance starts to decrease, the current is still increasing. At some point, the diode's forward current times resistance product (or the forward voltage) reaches a maximum and then rapidly decreases. This maximum, noted as V_{fp} in Figure 2, can reach values on the order of 200 volts for rapidly rising forward currents ($\Delta I/\Delta T \sim 1000A/\mu S$). The transient forward voltage will last on the order of 50 to 100 nanoseconds depending on the maximum value reached (References 1 and 2).

This parameter is significant since it will obviously affect the efficiency of the circuit in which the diode is used. It will also affect the electrical stress on the diode.

This parameter has yet to be measured for these diodes. The test setup for measuring this parameter has not been previously designed or built by the test lab

that performed the other measurements. Basically, it requires a circuit that (1) can deliver very fast risetime currents, (2) with reasonably high voltage capability, and (3) the setup must not contribute to the magnitude of the transient forward voltage due to inductance.

At this time, approaches and test equipment for measuring this parameter are being evaluated. If the appropriate test equipment is not available internally or if designing and building the test fixtures and circuitry is not economically feasible, outside sources will be sought for this test.

J.J. Erickson
Senior Scientist

References

1. Y.C. Liang, V.J. Gosbell, "Diode Forward and Reverse Recovery Model for Power Electronic SPICE Simulations", IEEE Transactions on Power Electronics, Vol. 5, No. 3, July 1990, pp. 346-356.

2. D.F. Courtney, "A Brief Analysis of the Transient Forward Voltage in Fast Diodes", IEEE Proceedings, Vol. 132, Pt.1, No.6, December 1985, pp. 277-280.

Table 1. Diode P/Ns, Vendors and Ratings

Mfr.	P/N	V(BD) (volts)	I(F) (A)	I(R) (nA)	t(RR) (nS)
Semtech	PFF0	1000	1.25	1.0 uA	75
Semtech	PFF6	600	1.25	1.0 uA	30
Semtech	SFF30	3000	0.36	1.0 uA	50
Motorola	MUR1100E	1000	1.0	N/A	75
Motorola	MUR160	600	1.0	N/A	50
VMI	1N6515	3000	1.5	1.0 uA	70
VMI	1N6615	1000	1.0	1.0 uA	70
Sensitron	SRS1100HE	1000	0.75	5.0uA	60
SSDI	SDR1M	1000	1.0	5.0 uA	70
Philips	BYV26E	1000	1.0	N/A	70
Philips	BYV26C	600	1.0	N/A	30

Table 2. Electrical Parameters and Test Conditions

Parameter	Symbol	Test conditions
Forward voltage	$V(f)_1$	I(f) - 10 mA
	$V(f)_2$	I(f) - 100 mA
	$V(f)_3$	I(f) - 250 mA
Reverse breakdown voltage	BV	I(r) - 50 uA
Reverse leakage current	I(L)	Rated peak inverse voltage
Reverse recovery time	$t(rr)_1$	*I(f)-250 mA, I(R)-500 mA, I(rr)-125 mA
	$t(rr)_2$	*I(f)-250 mA, I(R)-250 mA, I(rr)-125 mA

* Figure 1 shows waveforms illustrating the test conditions for t(rr)

Table 3. Test Device Serial Numbers

Mfr.	P/N	S/N
Semtech	PFF0	1-5
Semtech	PFF6	6-10
Semtech	SFF30	11-15
Motorola	MUR1100E	16-20
Motorola	MUR160	21-25
VMI	1N6515	26-30
VMI	1N6615	31-35,61-65*
Sensitron	SRS1100HE	36-40
SSDI	SDR1M	51-55
Philips	BYV26E	41-45
Philips	BYV26C	46-50

* There were two groups of 1N6615 test devices. The first group, S/N 31-35, was overstressed early in testing. A second group, S/N 61-65, was then substituted.

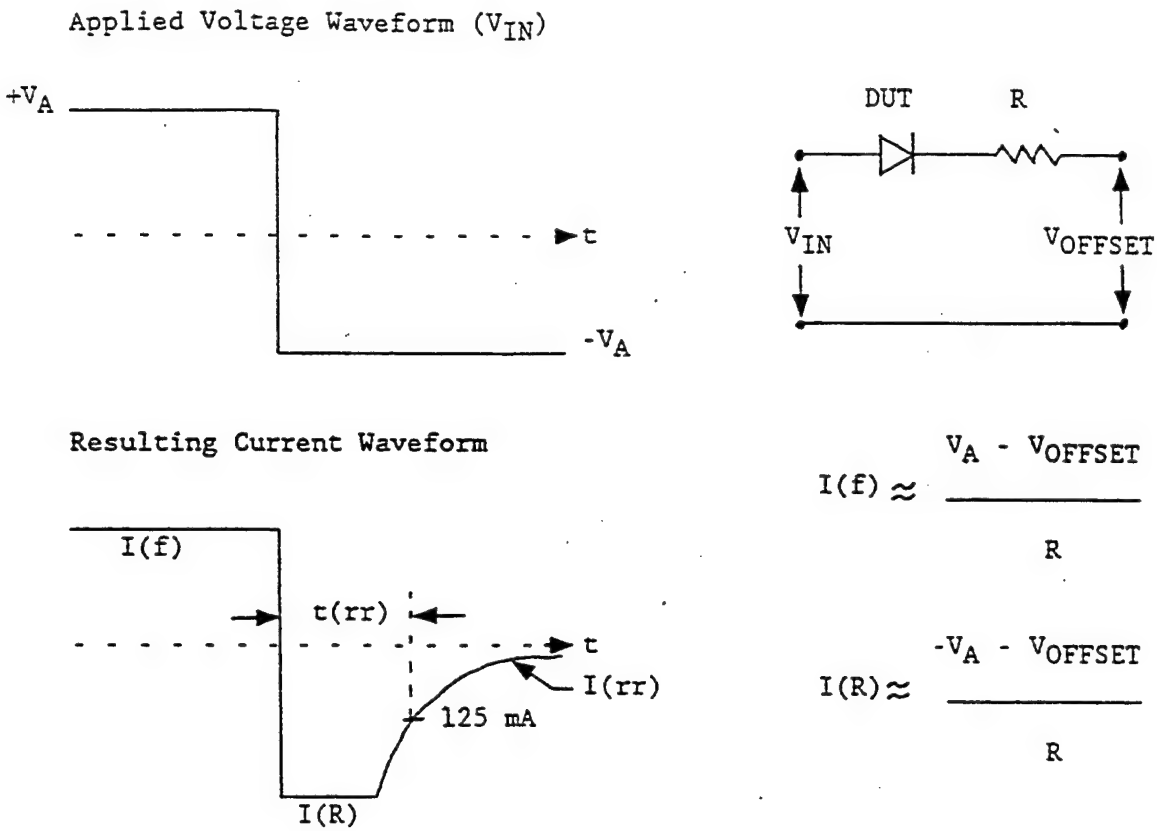

Figure 1. Waveforms and Schematic for t(rr) Measurement

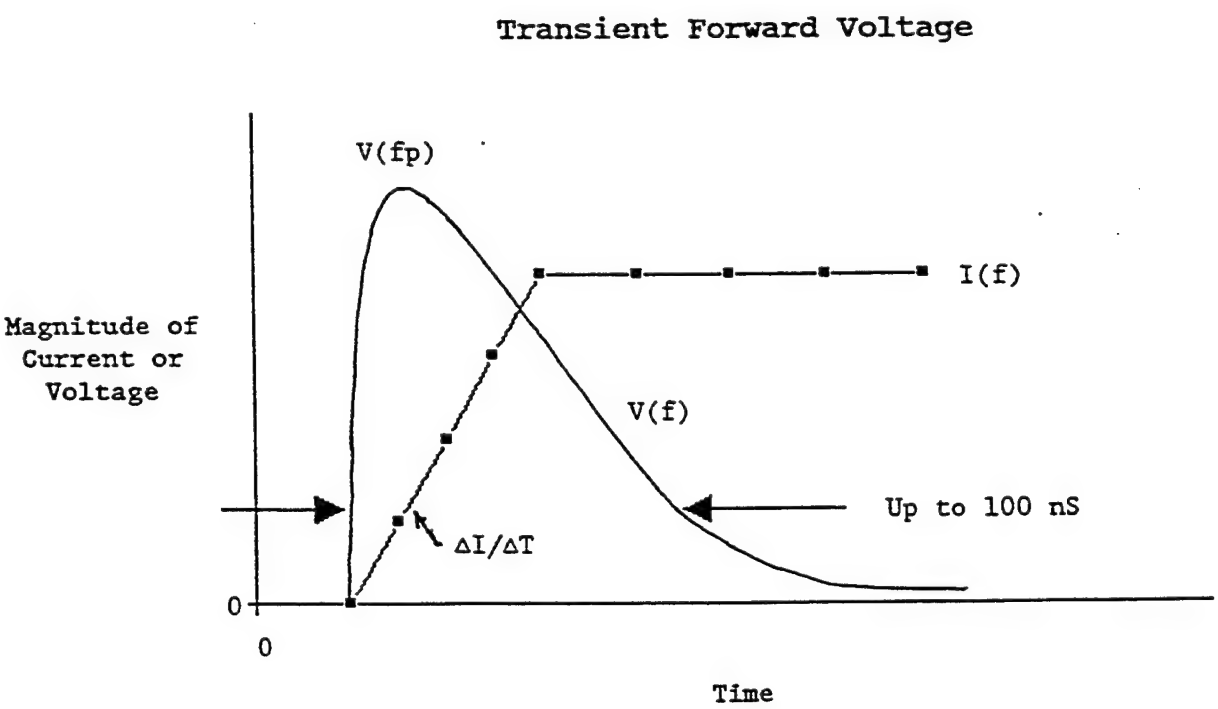

Figure 2. Waveforms for Transient Forward Voltage.

Table 4. V(f) in millivolts

Serial Number	10 mA			100 mA			250 mA		
	-55°C	25°C	125°C	-55°C	25°C	125°C	-55°C	25°C	125°C
1	896	634	414	1371	999	669	1657	1268	863
2	882	625	409	1320	970	656	1581	1221	840
3	942	642	413	1524	1047	682	1873	1356	888
4	939	642	412	1500	1041	677	1836	1344	881
5	904	628	407	1368	982	655	1644	1241	840
Average	913	634	411	1417	1008	668	1718	1286	862
6	761	621	424	879	736	566	935	807	644
7	762	608	425	883	738	567	940	812	648
8	763	612	428	883	738	571	939	810	650
9	763	609	423	886	739	567	940	810	644
10	764	608	426	891	744	572	949	819	654
Average	763	612	425	884	739	569	941	812	648
11	3385	2939	2291	Note 1	5227	4440	Note 1	6959	6010
12	3426	2986	2357	Note 1	5472	4708	Note 1	7387	6475
13	3410	2965	2306	Note 1	5252	4460	Note 1	7018	6078
14	3351	2913	2273	Note 1	5093	4390	Note 1	6679	5884
15	3329	2866	2193	Note 1	4994	4216	Note 1	6588	5665
Average	3380	2934	2284	--	5208	4443	--	6926	6022
16	896	663	437	1242	962	659	1342	1104	791
17	972	690	442	1388	1029	679	1508	1203	827
18	906	674	438	1317	1006	671	1447	1174	816
19	906	675	439	1302	1003	673	1425	1168	818
20	899	668	438	1287	993	669	1410	1153	811
Average	916	674	439	1307	999	670	1426	1160	813
21	793	613	430	929	783	598	999	874	695
22	798	616	433	936	788	601	1002	878	698
23	811	619	435	961	806	612	1035	905	716
24	807	616	432	950	800	608	1024	899	714
25	825	625	437	988	828	625	1069	936	738
Average	807	618	433	953	801	609	1026	898	712

Note 1: V(f) measurements at -55° for devices S/N 16-20 were not available.

Table 4. V(f) in millivolts (continued)

Serial Number	10 mA			100 mA			250 mA		
	-55°C	25°C	125°C	-55°C	25°C	125°C	-55°C	25°C	125°C
26	3036	2159	1356	4349	3107	2100	4980	3736	2610
27	2998	2167	1367	4190	3104	2153	4775	3720	2692
28	3059	2242	1455	4057	3018	2111	4534	3510	2529
29	2966	2138	1346	3951	2899	1982	4365	3347	2360
30	3027	2170	1368	4239	3112	2147	4803	3711	2663
Average	3017	2175	1378	4157	3048	2099	4691	3605	2571
31	Note 2	655	Note 2	Note 2	895	Note 2	Note 2	1042	Note 2
32	Note 2	679	Note 2	Note 2	980	Note 2	Note 2	1177	Note 2
33	Note 2	649	Note 2	Note 2	887	Note 2	Note 2	1043	Note 2
34	Note 2	675	Note 2	Note 2	947	Note 2	Note 2	1101	Note 2
35	Note 2	665	Note 2	Note 2	927	Note 2	Note 2	1091	Note 2
Average	--	665	--	--	927	--	--	1091	--
36	929	671	423	1473	1046	665	1700	1271	828
37	905	661	417	1366	995	645	1563	1188	793
38	909	665	421	1405	1022	660	1615	1235	819
39	898	658	420	1356	990	645	1535	1179	792
40	902	658	419	1344	988	646	1522	1174	790
Average	909	663	420	1389	1008	652	1587	1209	804
41	919	648	418	1429	1034	681	1734	1321	881
42	939	655	417	1517	1071	690	1872	1391	903
43	953	663	417	1586	1103	698	1971	1442	917
44	921	645	411	1442	1026	670	1755	1314	868
45	908	647	416	1420	1037	680	1725	1328	882
Average	928	652	416	1479	1054	684	1811	1359	890
46	825	572	369	1191	863	599	1426	1097	778
47	824	576	372	1197	875	605	1437	1116	920
48	847	581	379	1307	909	627	1604	1180	944
49	809	572	372	1150	855	598	1369	1081	874
50	803	570	370	1122	843	591	1327	1060	860
Average	822	574	372	1193	869	604	1433	1107	875

Note 2: Devices S/N 31-35 were overstressed after measuring breakdown voltage at 25°C.

Table 4. V(f) in millivolts (continued)

Serial Number	10 mA			100 mA			250 mA		
	-55°C	25°C	125°C	-55°C	25°C	125°C	-55°C	25°C	125°C
51	800	642	437	1100	995	752	1291	1246	974
52	797	636	427	1065	950	715	1226	1166	915
53	801	641	436	1094	987	747	1280	1233	969
54	801	640	433	1086	982	745	1267	1227	968
55	801	646	440	1095	992	743	1274	1230	953
Average	800	641	435	1088	981	740	1268	1220	956
61	Note 3	659	Note 3	Note 3	926	Note 3	Note 3	1091	Note 3
62	Note 3	645	Note 3	Note 3	871	Note 3	Note 3	1015	Note 3
63	Note 3	648	Note 3	Note 3	882	Note 3	Note 3	1035	Note 3
64	Note 3	654	Note 3	Note 3	881	Note 3	Note 3	1019	Note 3
65	Note 3	653	Note 3	Note 3	861	Note 3	Note 3	964	Note 3
Average	--	652	--	--	884	--	--	1025	--

Note 3. V(f) measurements on devices 61-65 at -55°C and 125°C were not available.

Table 5. Breakdown Voltages (BV) in volts and Leakage Currents (IL) in nA

Serial Number	BV			IL		
	-55° C	25°C	125°C	-55° C	25°C	125°C
1	1174	1296	1407	12.0	50.8	11900.0
2	1156	1271	1376	6.4	61.0	12100.0
3	1209	1329	1444	11.8	80.0	13100.0
4	1195	1311	1424	10.0	80.0	10700.0
5	1102	1207	1309	10.0	80.0	12100.0
Average	1167	1283	1392	10.0	70.4	11980.0
6	563	621	Note 1.	Note 1.	155	29900
7	549	608	642	Note 1.	54.8	8490
8	553	612	649	Note 1.	240	9350
9	549	609	Note 1.	Note 1.	239	17900
10	549	608	Note 1.	Note 1.	60	73000
Average	553	612	646	--	149.8	27728.0
11	5201	5730	Note 2.	4.1	235	Note 2.
12	4663	4910	Note 2.	2.1	195	Note 2.
13	5195	5737	Note 2.	1.5	183	Note 2.
14	5234	5678	Note 2.	2	224	Note 2.
15	4776	5033	Note 2.	2.2	344	Note 2.
Average	5014	5418	--	2.4	236.2	--
16	970	1132	1180	Note 1.	2010	23700
17	Note 1.	1294	1386	402	1210	14800
18	Note 1.	1133	1247	98	100	21000
19	Note 1.	1187	1246	80	121	21200
20	Note 1.	1141	1228	80	104	18100
Average	970	1177	1257	165.0	709.0	19760.0
21	671	742	Note 1.	10	161	13100
22	709	776	Note 1.	80	305	7270
23	700	807	Note 1.	99	327	7150
24	707	765	Note 1.	14	455	26300
25	723	787	Note 1.	117	378	9370
Average	702	775	--	64.0	325.2	12638.0

Note 1: Data not available at time report was generated.
Note 2: Devices not tested at 125°C to avoid overheating.

Table 5. Breakdown Voltages (BV) in volts and Leakage Currents (IL) in nA (continued)

Serial Number	BV			IL		
	-55° C	25°C	125°C	-55° C	25°C	125°C
26	5352	5879	Note 2.	1.1	275	30000
27	5577	6174	Note 2.	0.8	266	36000
28	5274	5856	Note 2.	0.5	306	43000
29	5506	6066	Note 2.	0.2	218	33600
30	5583	6143	Note 2.	0.6	238	35400
Average	5458	6024	--	0.6	260.6	35600.0
36	1225	1357	1491	8.8	30	6890
37	1219	1339	1420	8.2	51	10600
38	1287	1414	1543	10	40	6840
39	1156	1269	1388	8.6	52.2	5030
40	1197	1323	1450	12	40	7320
Average	1217	1340	1458	9.5	42.6	7336.0
41	1224	1344	1459	10	60	13500
42	1243	1364	1479	10	80	14000
43	1244	1379	1506	5.4	48	14100
44	1182	1303	1419	6	80	12200
45	1213	1334	1415	10	84	17400
Average	1221	1345	1456	8.3	70.4	14240.0
46	749	816	883	6.2	57	8810
47	777	850	918	4	25.4	7720
48	792	870	933	26.2	105	6860
49	737	807	868	14	85	9070
50	744	811	848	113	350	8960
Average	760	831	890	32.7	124.5	8284.0
51	1117	1221	Note 2.	6	129	65500
52	1139	1240	Note 2.	8	80	59900
53	1127	1224	Note 2.	11	133	53300
54	1165	1268	Note 2.	20	168	65900
55	1125	1233	Note 2.	10	178	57900
Average	1135	1237	--	11.0	137.6	60500.0

Note 2: Devices not tested at 125°C to avoid overstressing.

Table 5. Breakdown Voltages (BV) in volts and Leakage Currents (IL) in nA (continued)

Serial Number	BV			IL		
	-55° C	25°C	125°C	-55° C	25°C	125°C
61	Note 1.	1277	Note 1.	Note 1.	60	Note 1.
62	Note 1.	1209	Note 1.	Note 1.	40	Note 1.
63	Note 1.	1169	Note 1.	Note 1.	28	Note 1.
64	Note 1.	1289	Note 1.	Note 1.	30	Note 1.
65	Note 1.	1000	Note 1.	Note 1.	50	Note 1.
Average	--	1189	--	--	41.6	--

Note 1: Data not available at time report was generated.
Note 2: Devices not tested at 125°C to avoid overheating.

Table 6. Measured t(rr)1 and t(rr)2 in nS

Serial Number	t(rr)1				t(rr)2			
	-55° C	25°C	85°C	125°C	-55° C	25°C	85°C	125°C
1	33.5	66.7	102	155	46.6	96.6	150	227
2	33.8	65.4	100	153	44.7	93.7	148	224
3	32.3	60.4	95.7	140	43.2	90.7	139	205
4	31.5	61.6	95.2	141	42.4	87.9	138	205
5	29.3	59.1	89.1	136	40.4	83.7	132	196
Average	32.1	62.6	96.4	145.0	43.5	93.7	141.4	211.4
6	25.7	46.6	83.4	122	33.3	65	104	154
7	25.4	46.6	82.9	122	32.9	65.9	106	155
8	25.5	46.9	85.3	123	33.5	65.4	109	158
9	23.8	41.7	69.2	111	30.5	59.4	95.3	140
10	24.5	44.5	78.1	117	32.5	63.7	101	149
Average	25.0	45.3	79.8	119.0	32.5	65.4	103.1	151.2
11	37.9	61.9	94.4	Note 1	58.8	95.3	135	Note 1
12	39	63.1	94.6	Note 1	59.7	98.8	141	Note 1
13	38.2	61.4	99.5	Note 1	59.7	97.9	142	Note 1
14	38.6	63.1	96.2	Note 1	59.7	96.4	141	Note 1
15	36.9	57.4	92.1	Note 1	55.4	91.8	133	Note 1
Average	38.1	61.4	95.4		58.7	97.3	138.4	
16	21.8	35.6	62.2	95.9	27.9	46.9	81.2	118
17	25.4	39.7	71.4	111	32.2	54.7	92.5	134
18	22.1	35.4	65	102	29.2	47.5	83.9	122
19	22.3	35.4	63.7	99.9	28.4	47.7	82.2	121
20	21.9	35.1	62	93.7	28.2	46.6	79.5	117
Average	22.7	36.2	64.9	100.5	29.2	49.7	83.9	122.4
21	21.6	36.3	58.6	85.6	29	49.9	81	115
22	22.7	38.4	61.9	90.5	30.7	52.3	84.8	120
23	22.1	36.8	58.2	84.9	29.2	50	82	116
24	20.2	33.7	54.3	77.5	26.8	46.2	74.1	105
25	19.9	32.9	51.3	70.7	26.1	44.3	71	99.5
Average	21.3	35.6	56.9	81.8	28.4	50.7	78.6	111.1

Note 1: Devices S/N 11-15 were not tested at 125°C to avoid overheating.

Table 6. Measured t(rr)1 and t(rr)2 in nS (continued)

Serial Number	t(rr)1				t(rr)2			
	-55° C	25°C	85°C	125°C	-55° C	25°C	85°C	125°C
26	37.6	95.6	215	391	51.9	124	294	520
27	38.8	97.3	221	373	53.3	128	298	510
28	36.1	84.3	216	384	50	115	292	513
29	38.1	88.9	216	377	52.6	122	286	505
30	37.3	95.8	224	415	52	130	318	560
Average	37.6	92.4	218.4	388.0	52.0	122.3	297.6	521.6
36	26	45.1	87.5	135	35.2	62.1	115	174
37	25.7	43.8	82	129	33.7	58.5	108	165
38	30.4	53.9	104	162	42.1	75.1	139	210
39	27.4	45.5	88.3	140	36.2	63.9	118	177
40	27.1	47.2	94.1	145	36.9	66.3	122	185
Average	27.3	47.1	91.2	142.2	36.8	65.2	120.4	182.2
41	33.2	61.3	104	154	46.3	88.7	151	225
42	31.7	58.1	98.7	148	45.1	84.4	145	214
43	32.7	59.9	103	152	46.7	86.6	150	216
44	33.8	60.7	105	155	46.4	87.1	152	226
45	33.1	59.5	101	150	45.3	86.2	148	220
Average	32.9	59.9	102.3	151.8	46.0	86.6	149.2	220.2
46	15.9	28.9	49.5	72.4	21.1	40.8	71.9	110
47	16.5	29.9	50.7	74	21.9	42.2	73.8	113
48	16	29.6	51.5	76.3	22	42.1	75.5	116
49	16.1	29.7	49.7	75.3	21.3	41.2	72.3	113
50	16.2	29.5	50.7	75.7	21.5	41.5	73	114
Average	16.1	29.5	50.4	74.7	21.6	41.7	73.3	113.2
51	32.7	49	70.9	98.4	44.6	69.9	106	145
52	35.3	49.9	74.7	104	46.7	72.2	110	149
53	33.4	50.3	76.3	106	46.5	73.1	114	157
54	32	48.4	72.2	99.4	45	70	107	149
55	36.2	52.1	80.6	110	48.4	75.9	116	161
Average	33.9	49.9	74.9	103.6	46.2	71.7	110.6	152.2

Table 6. Measured t(rr)1 and t(rr)2 in nS (continued)

Serial Number	t(rr)1				t(rr)2			
	-55° C	25°C	85°C	125°C	-55° C	25°C	85°C	125°C
61	32.4	54.2	99.5	150	43.5	76.4	133	196
62	36.7	61.2	118	178	49.0	86.6	154	230
63	37.1	60.3	119	177	49.2	88.3	155	228
64	34.6	58.2	112	168	46.7	82.8	144	214
65	36.7	62.3	115	166	49.3	86.9	148	215
Average	35.5	59.2	112.7	167.8	47.5	83.8	146.8	216.6

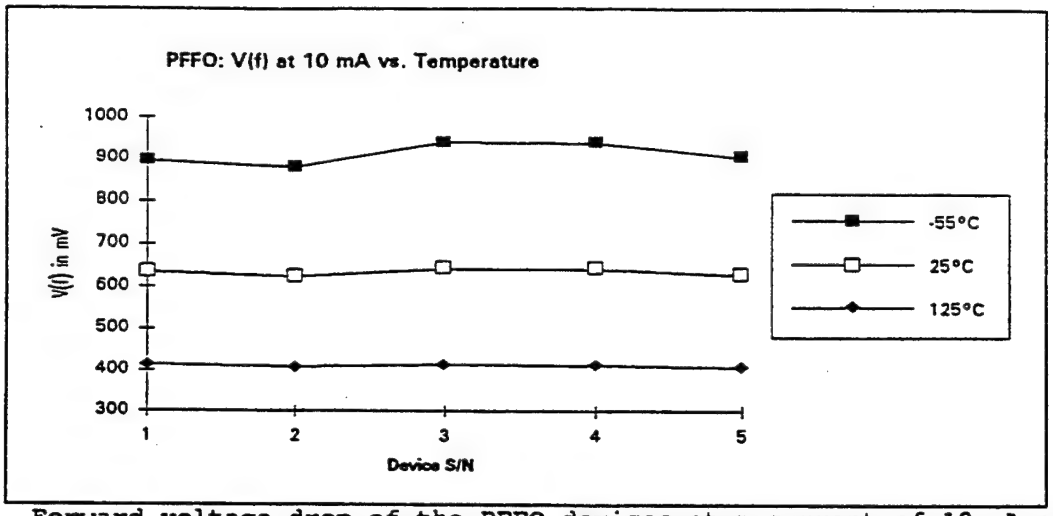

Figure V1. Forward voltage drop of the PFFO devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some variation at -55°C.

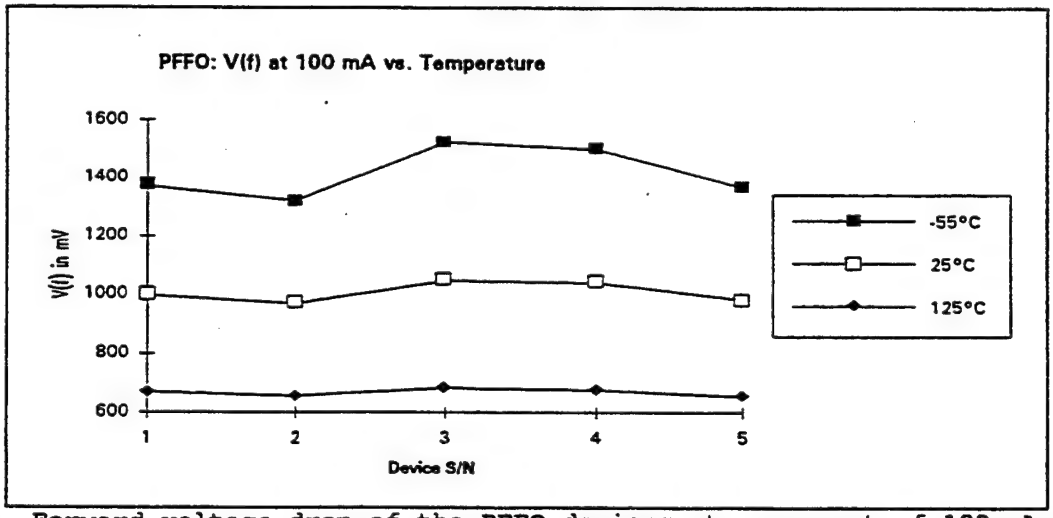

Figure V2. Forward voltage drop of the PFFO devices at a current of 100 mA plotted for three temperatures. As in Figure V1, the largest variation in behavior from device to device occurs at -55°C.

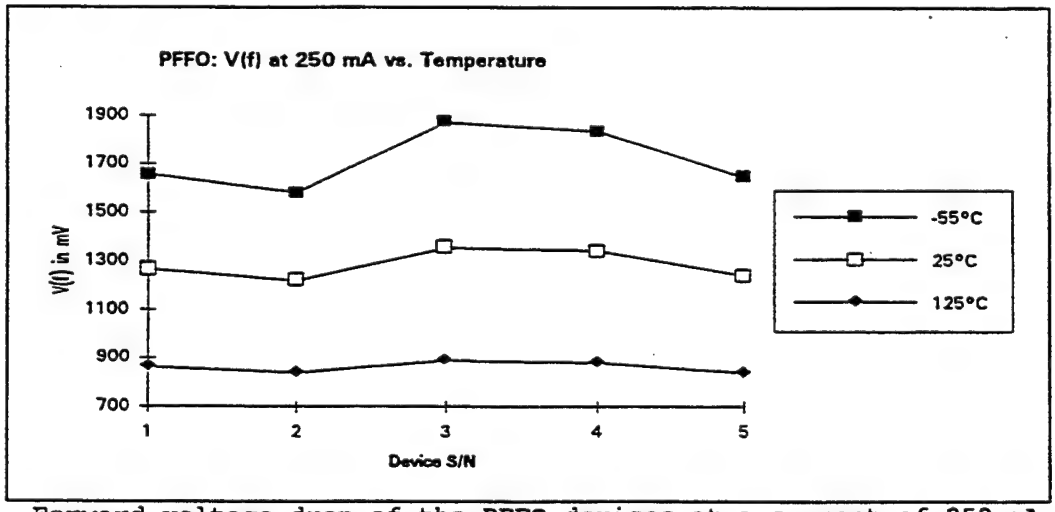

Figure V3. Forward voltage drop of the PFFO devices at a current of 250 mA plotted for three temperatures. Again, the largest difference in behavior from device to device occurs at -55°C.

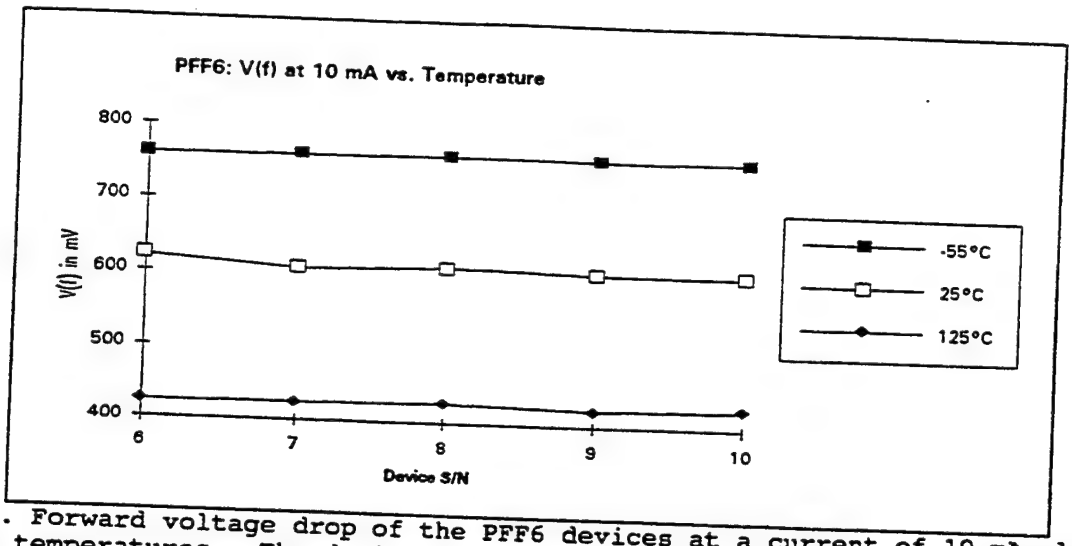

Figure V4. Forward voltage drop of the PFF6 devices at a current of 10 mA plotted for three temperatures. The devices have very uniform behavior at all temperatures.

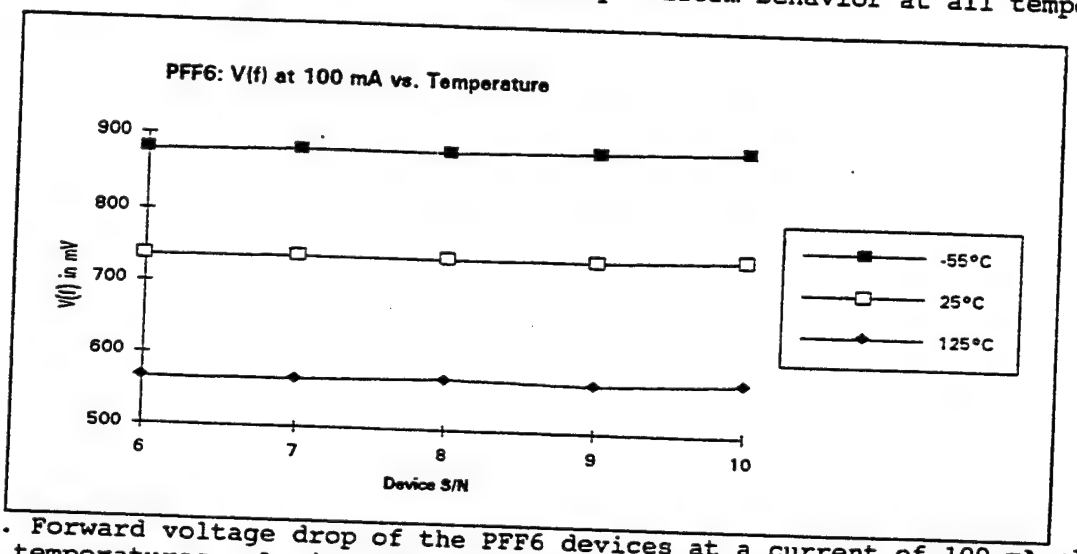

Figure V5. Forward voltage drop of the PFF6 devices at a current of 100 mA plotted for three temperatures. As in Figure V4, the devices have very uniform behavior at all temperatures.

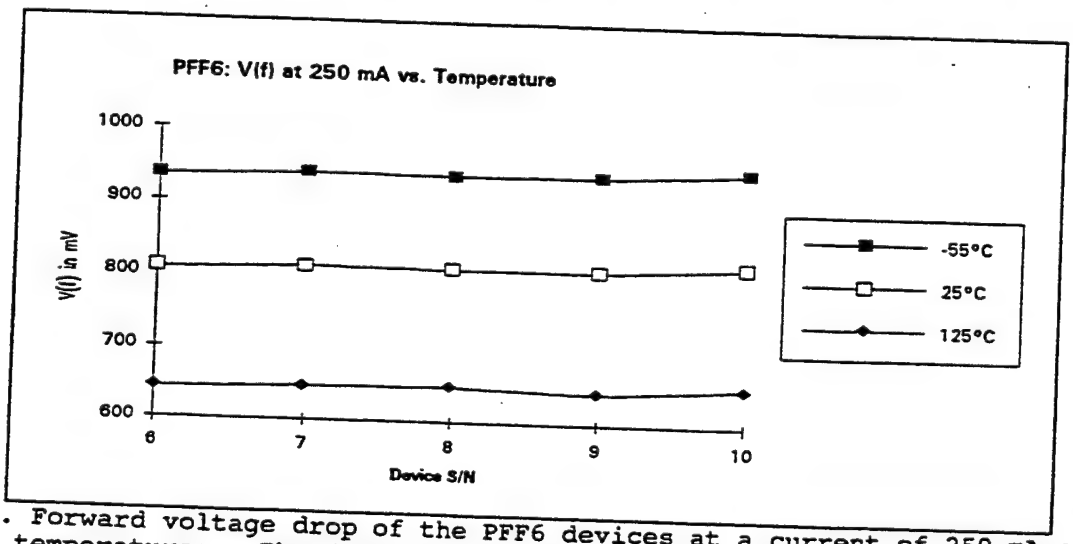

Figure V6. Forward voltage drop of the PFF6 devices at a current of 250 mA plotted for three temperatures. The devices have very uniform behavior at all temperatures.

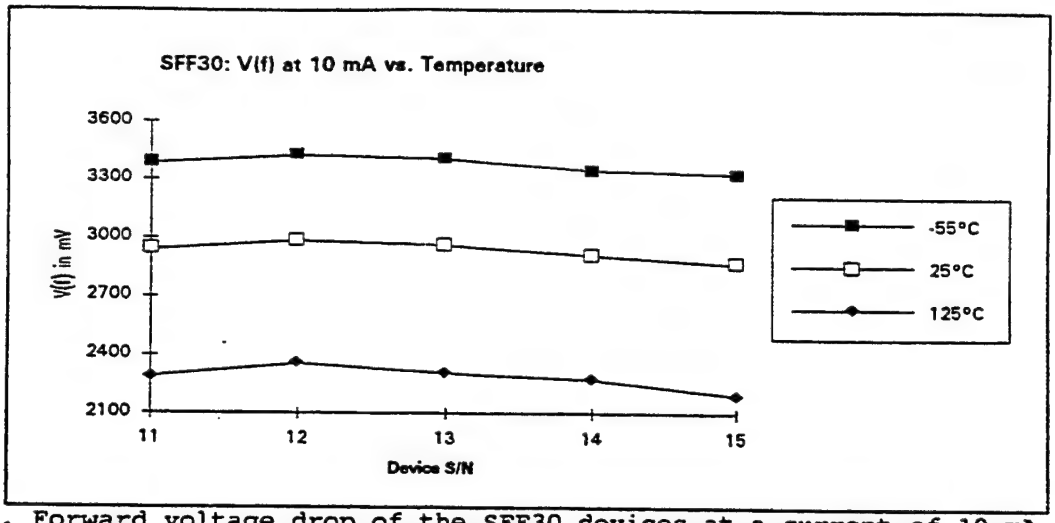

Figure V7. Forward voltage drop of the SFF30 devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior at -55 and 25°C.

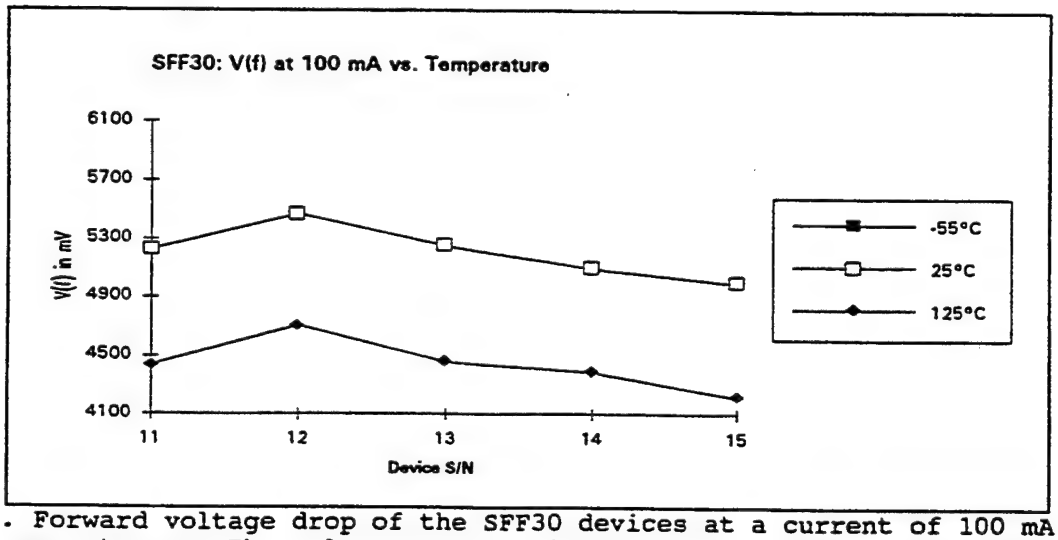

Figure V8. Forward voltage drop of the SFF30 devices at a current of 100 mA plotted for two temperatures. The values vary considerably from device to device. (-55°C data was not available.)

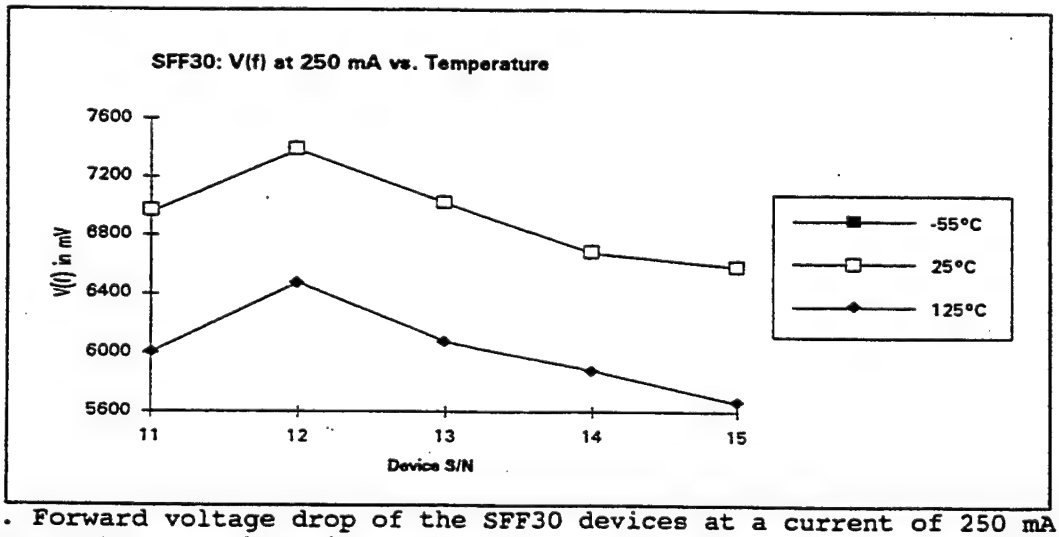

Figure V9. Forward voltage drop of the SFF30 devices at a current of 250 mA plotted for two temperatures. There is a very large spread in values (almost a full volt) from device to device.(-55°C data was not available.)

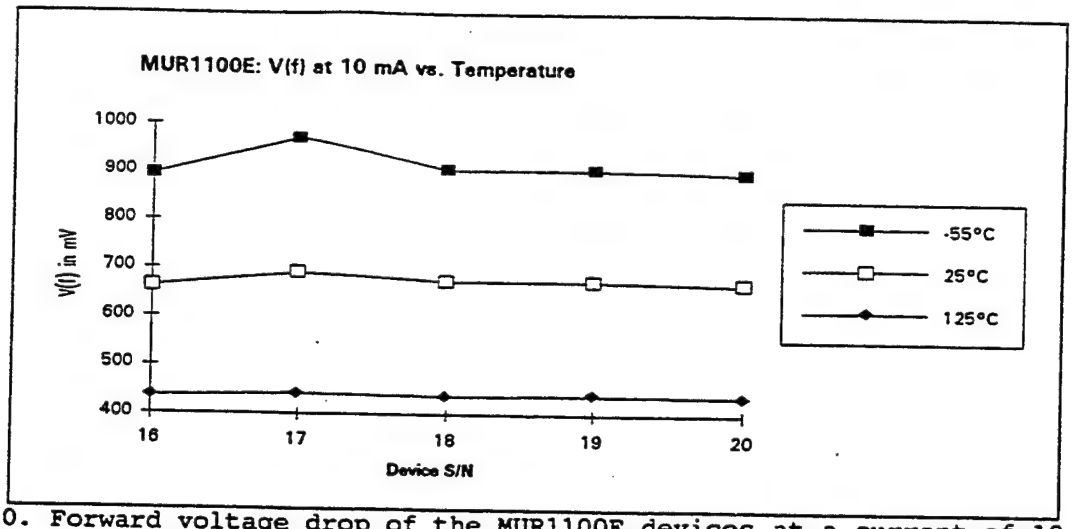

Figure V10. Forward voltage drop of the MUR1100E devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some variation at -55°C.

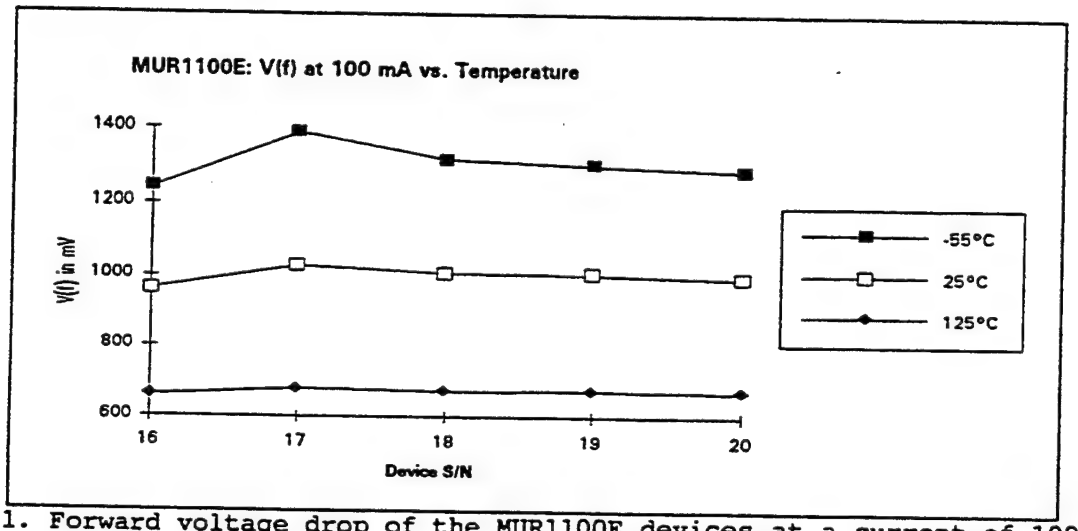

Figure V11. Forward voltage drop of the MUR1100E devices at a current of 100 mA plotted for three temperatures. As in Figure V10, the devices have fairly uniform behavior at 25°C and 125°C with some variation at -55°C.

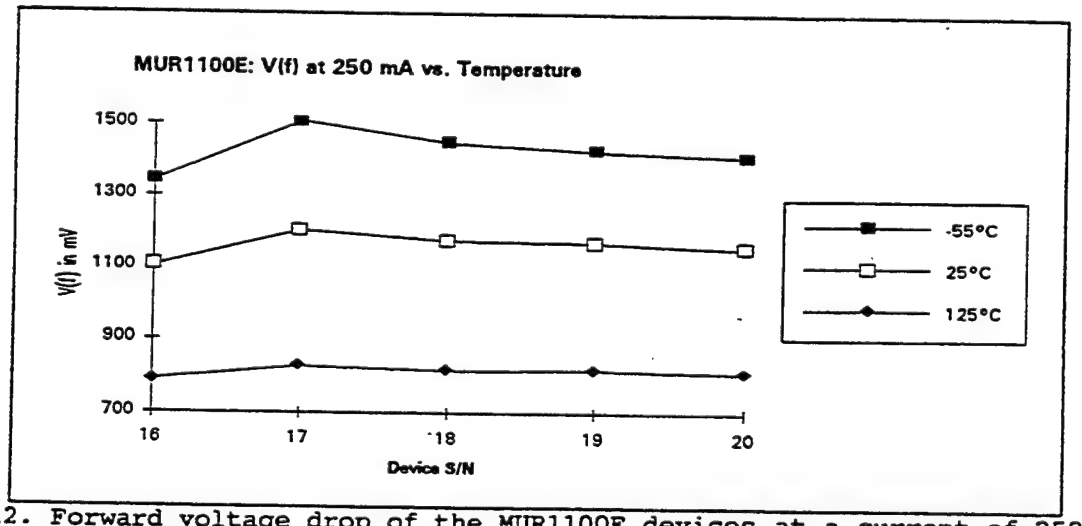

Figure V12. Forward voltage drop of the MUR1100E devices at a current of 250 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

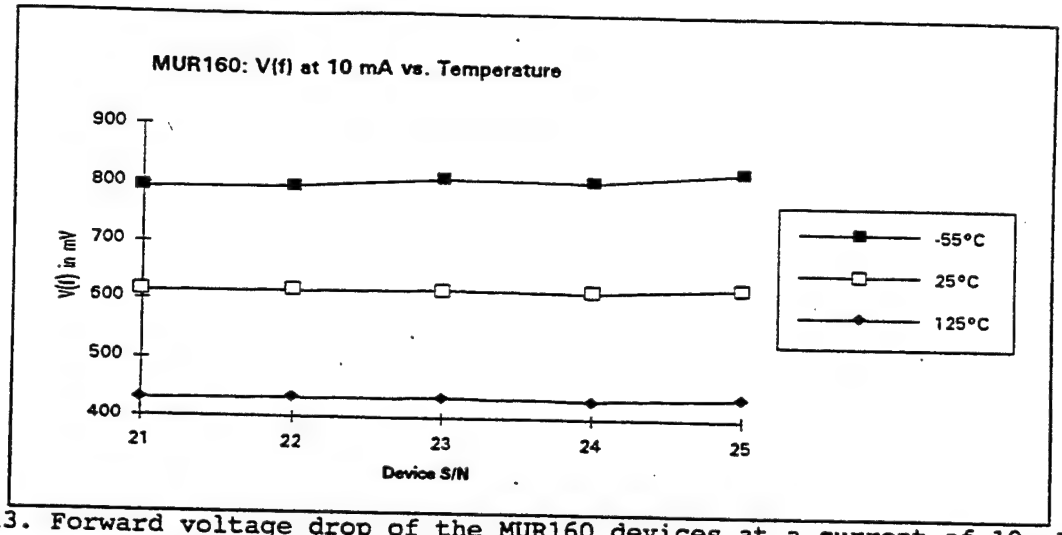

Figure V13. Forward voltage drop of the MUR160 devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior at all three of the temperatures.

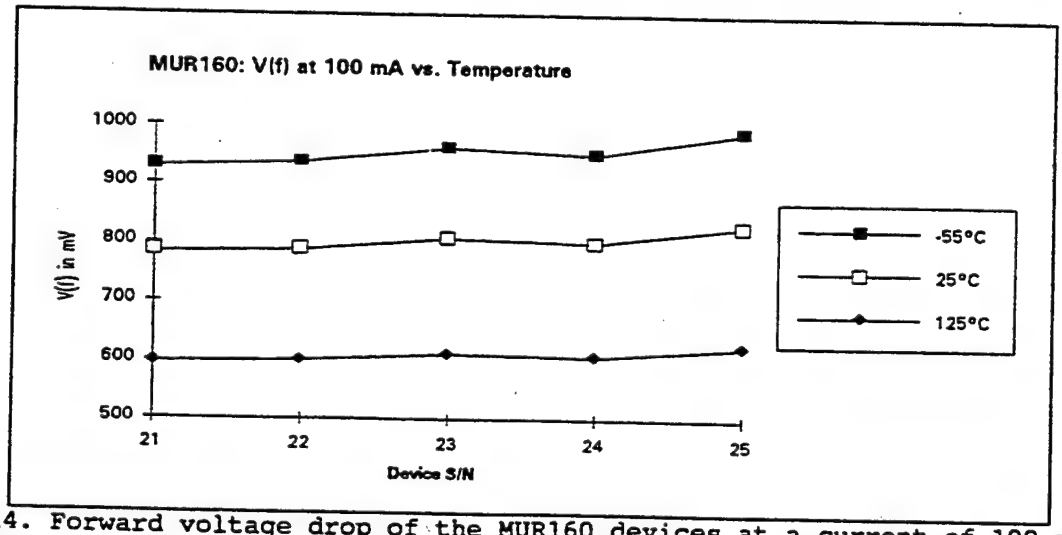

Figure V14. Forward voltage drop of the MUR160 devices at a current of 100 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

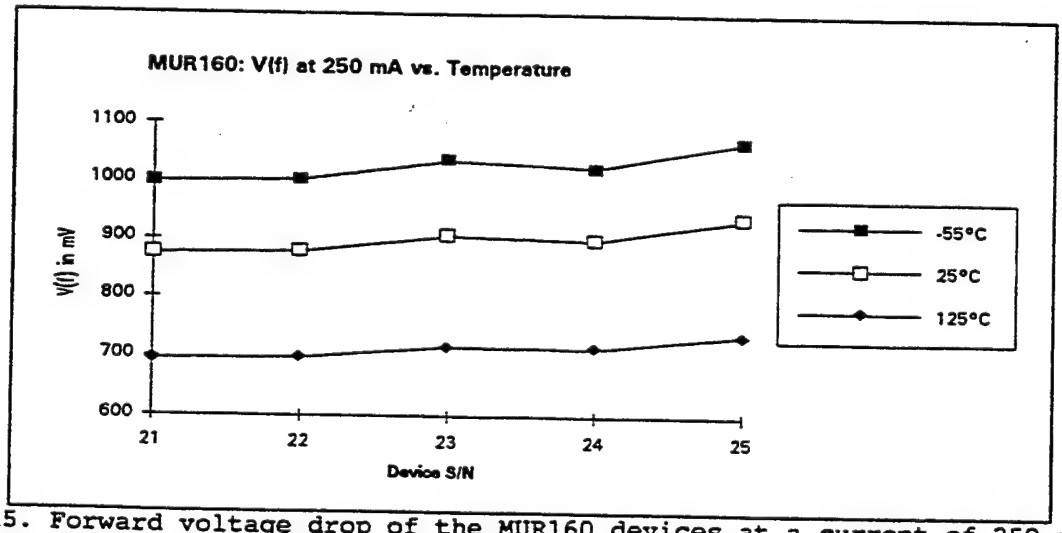

Figure V15. Forward voltage drop of the MUR160 devices at a current of 250 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

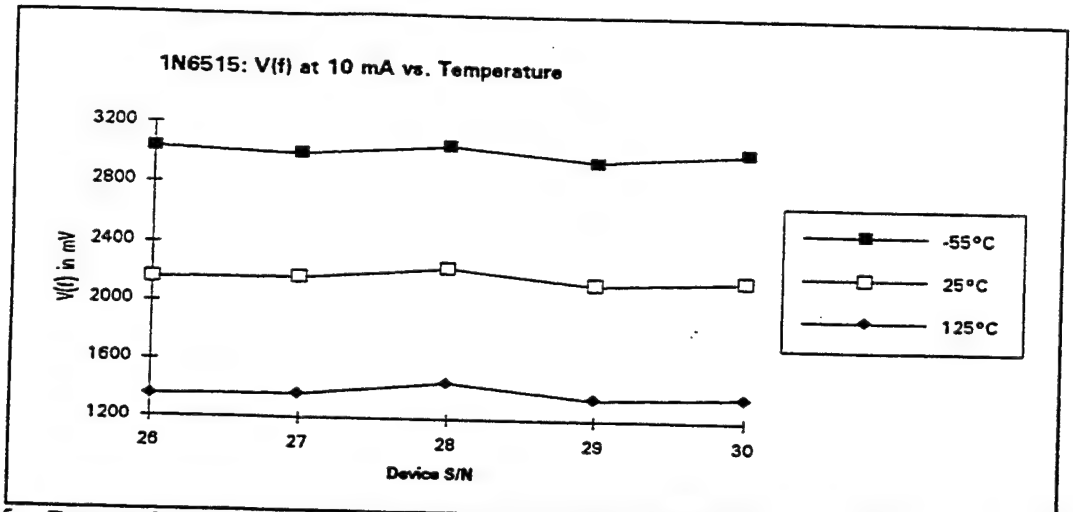

Figure V16. Forward voltage drop of the 1N6515 devices at a current of 10 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at all three temperatures.

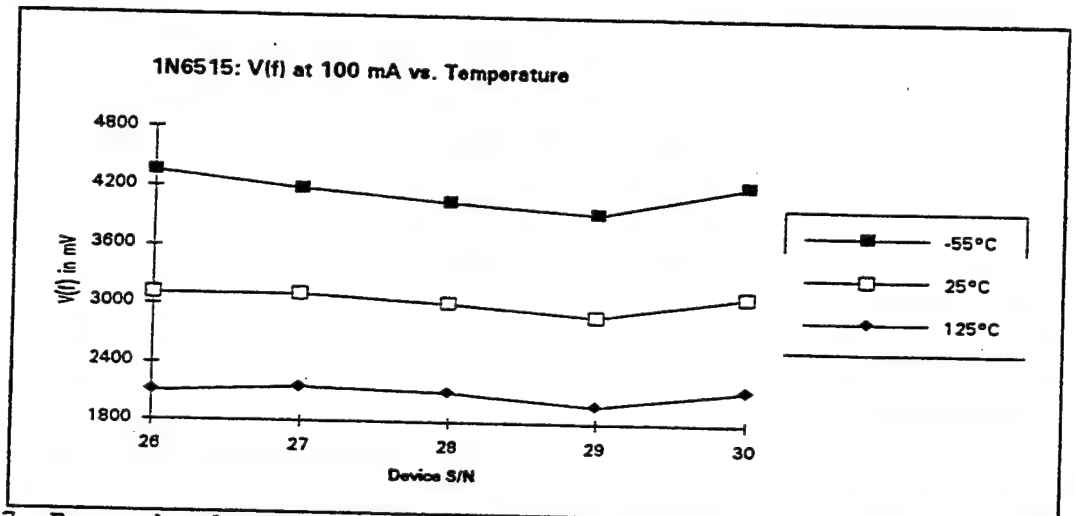

Figure V17. Forward voltage drop of the 1N6515 devices at a current of 100 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

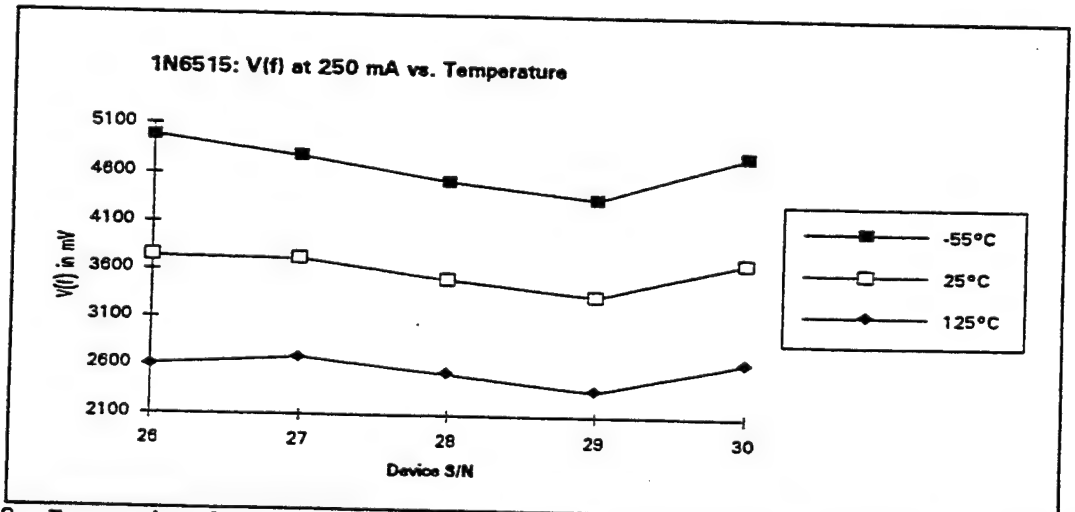

Figure V18. Forward voltage drop of the 1N6515 devices at a current of 250 mA plotted for three temperatures. The devices have fairly large differences in their values from device to device.

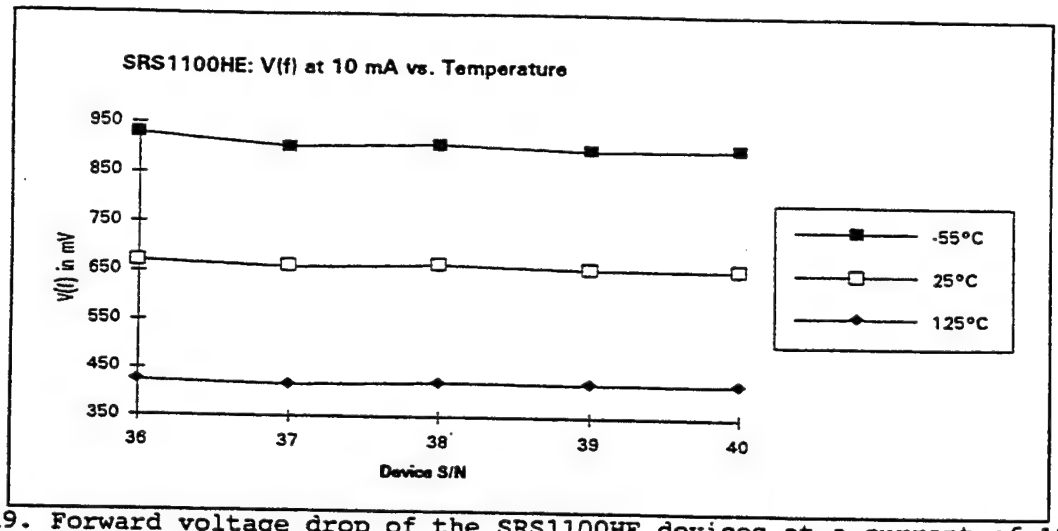

Figure V19. Forward voltage drop of the SRS1100HE devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior at all temperatures.

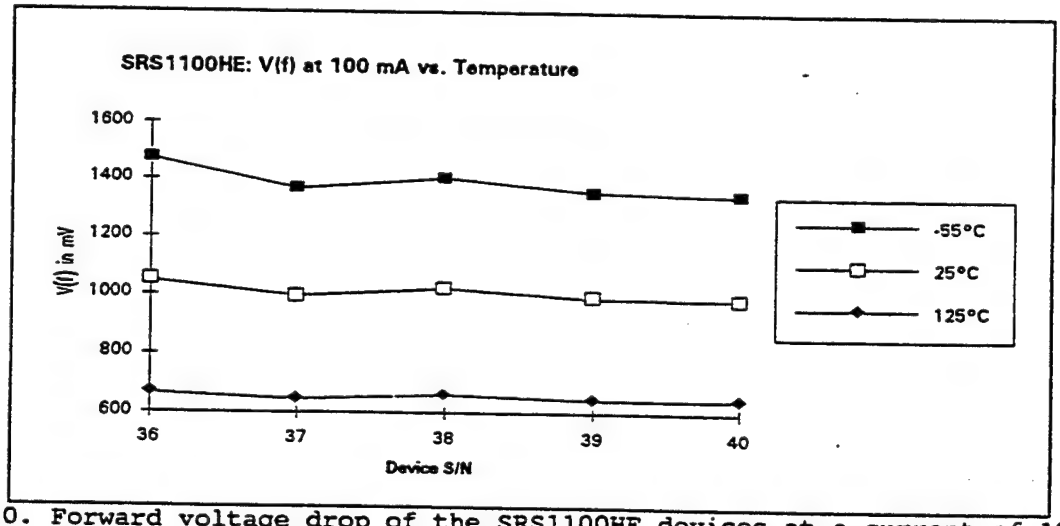

Figure V20. Forward voltage drop of the SRS1100HE devices at a current of 100 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

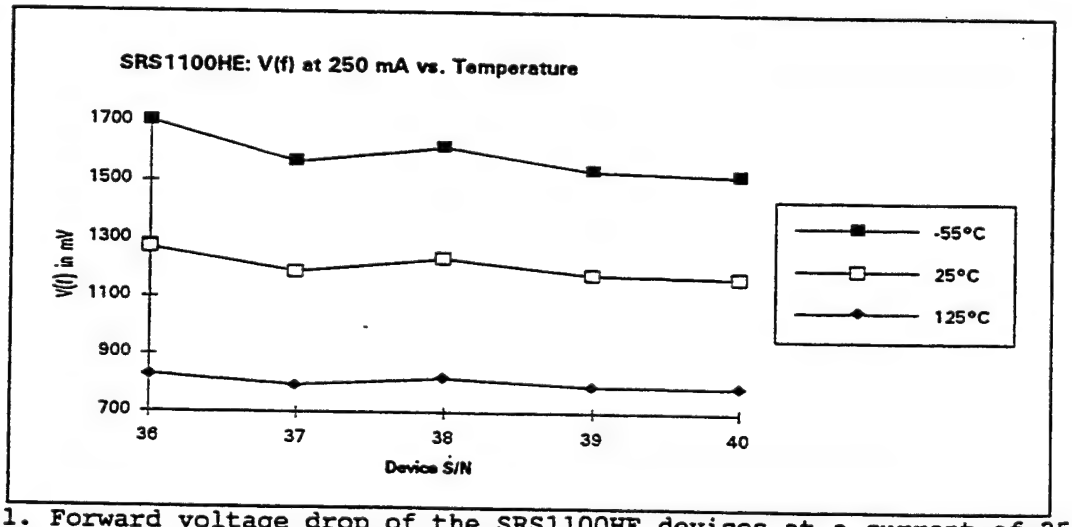

Figure V21. Forward voltage drop of the SRS1100HE devices at a current of 250 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

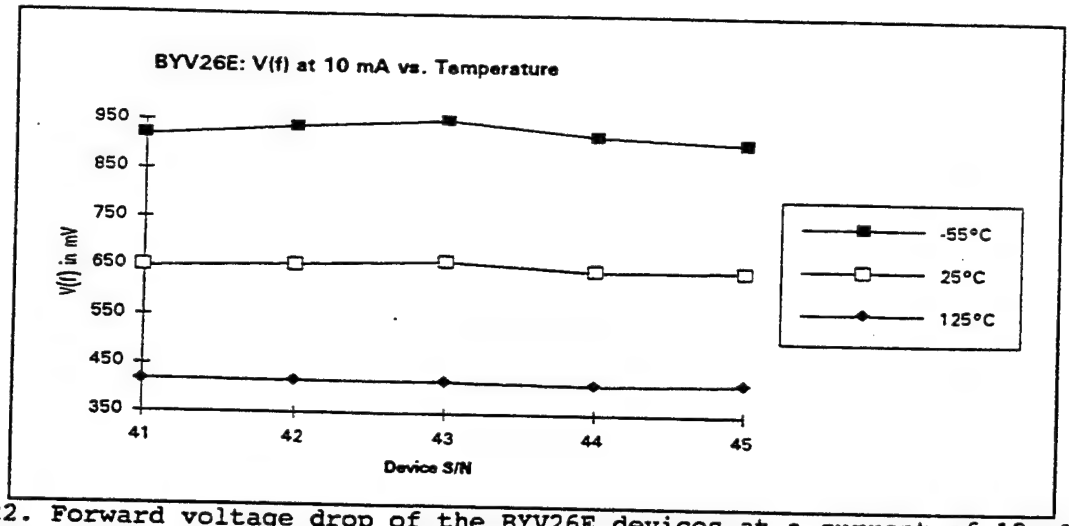

Figure V22. Forward voltage drop of the BYV26E devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior at all three temperatures.

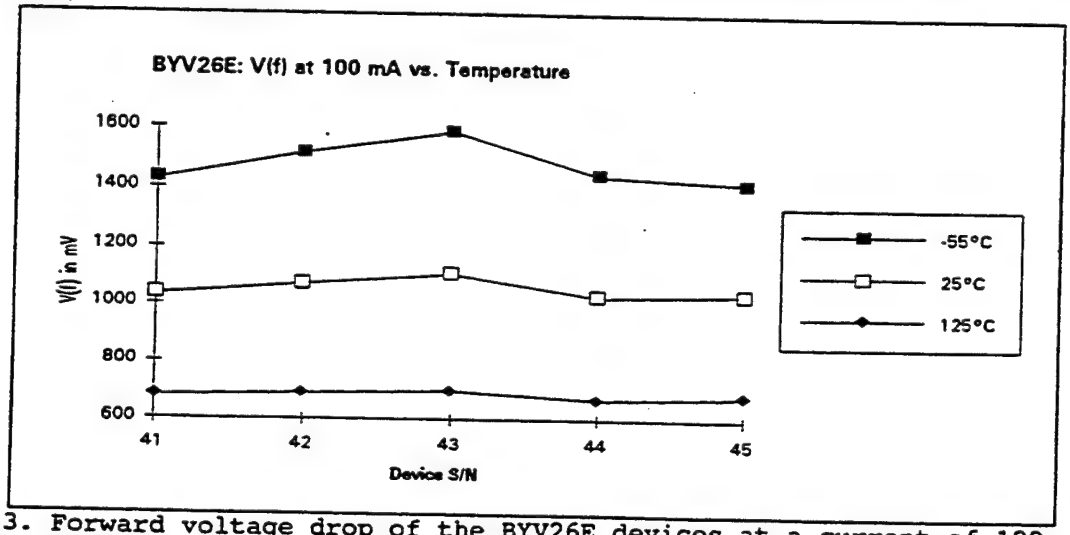

Figure V23. Forward voltage drop of the BYV26E devices at a current of 100 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

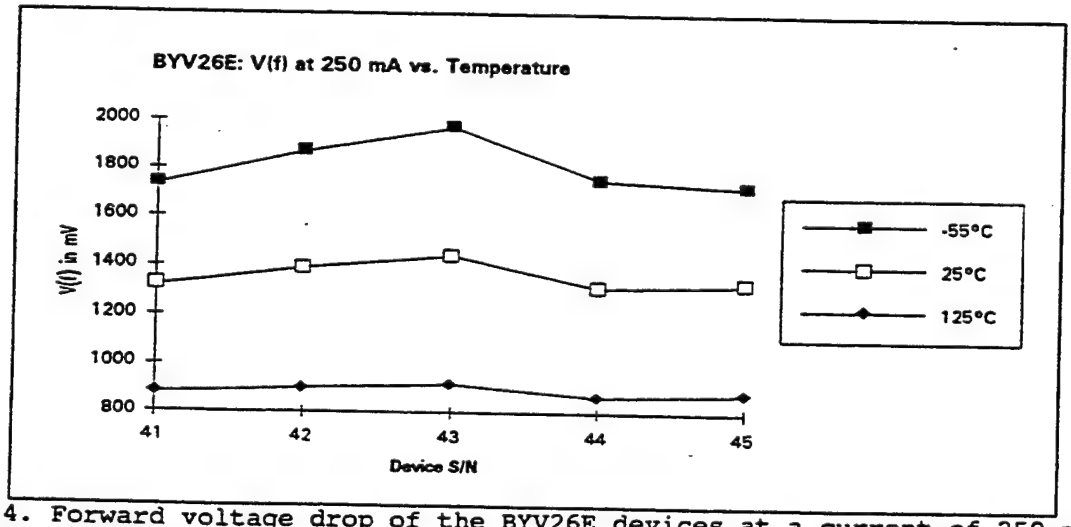

Figure V24. Forward voltage drop of the BYV26E devices at a current of 250 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

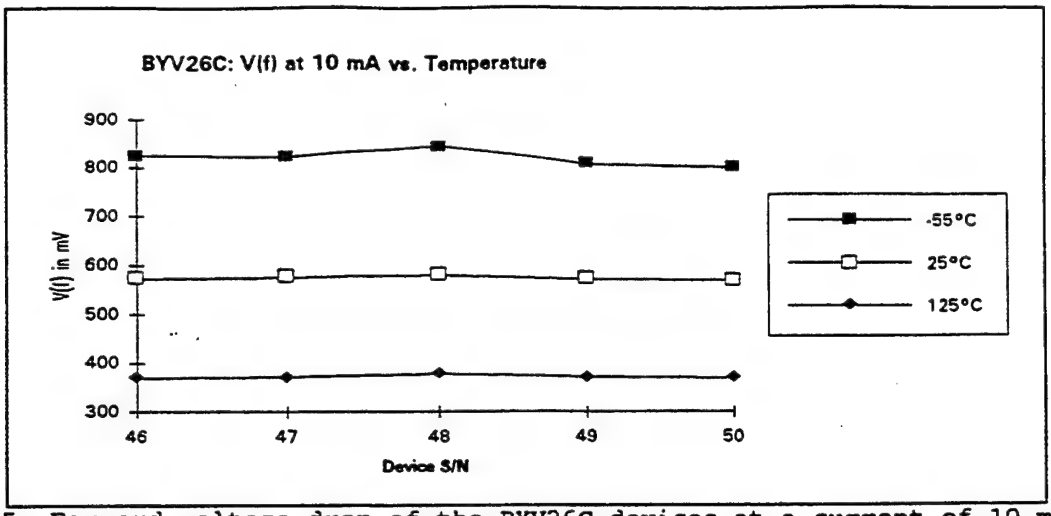

Figure V25. Forward voltage drop of the BYV26C devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior for all three temperatures.

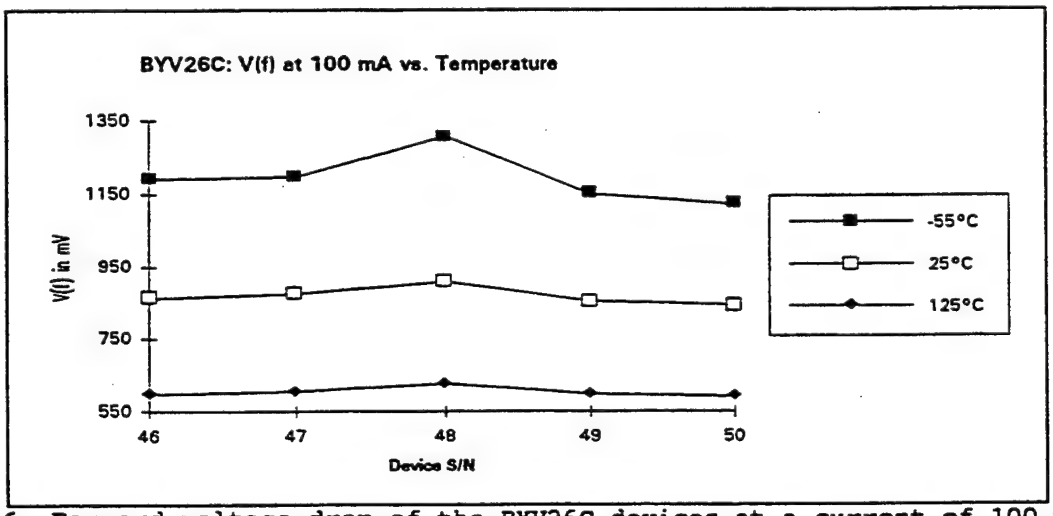

Figure V26. Forward voltage drop of the BYV26C devices at a current of 100 mA plotted for three temperatures. The devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

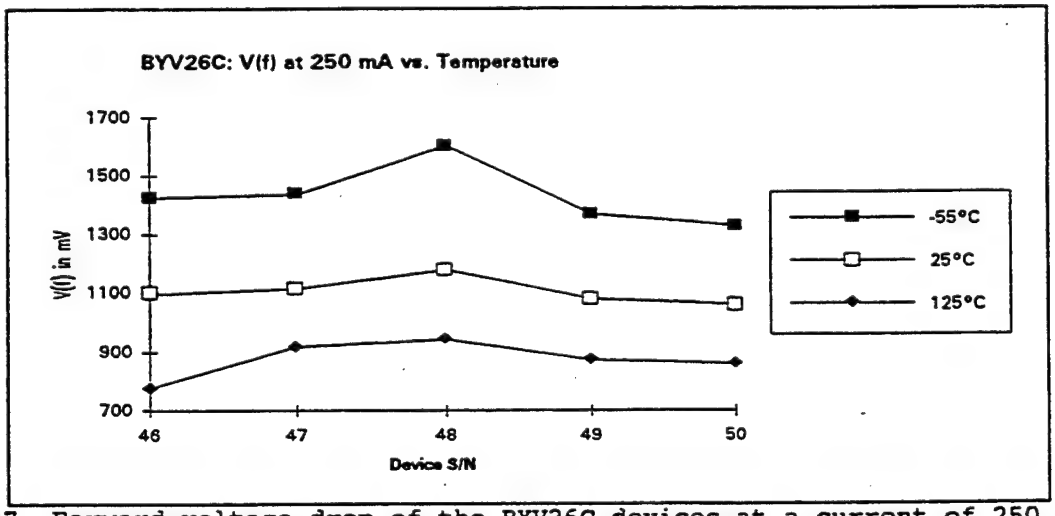

Figure V27. Forward voltage drop of the BYV26C devices at a current of 250 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at 25°C and 125°C with some larger variation at -55°C.

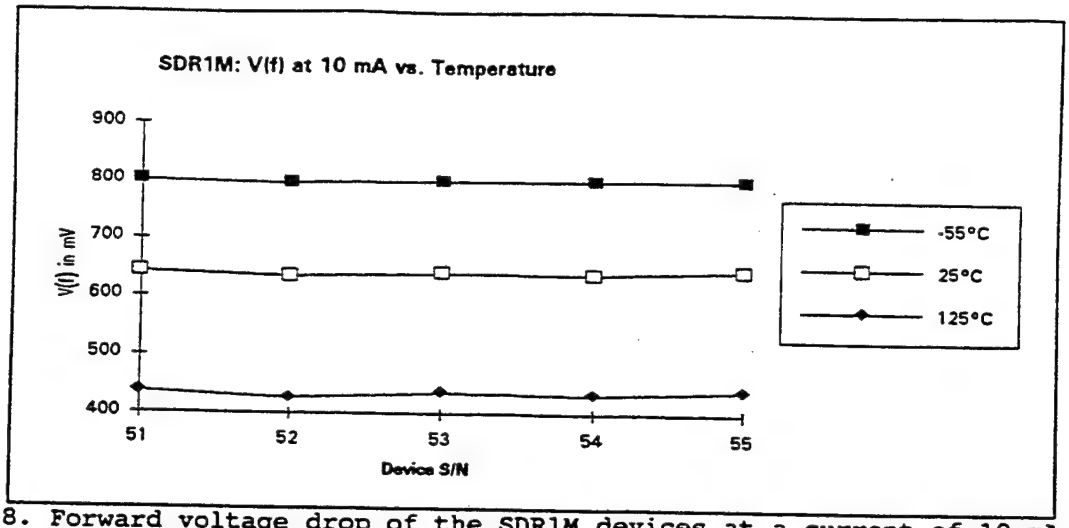

Figure V28. Forward voltage drop of the SDR1M devices at a current of 10 mA plotted for three temperatures. The devices have fairly uniform behavior for all three temperatures.

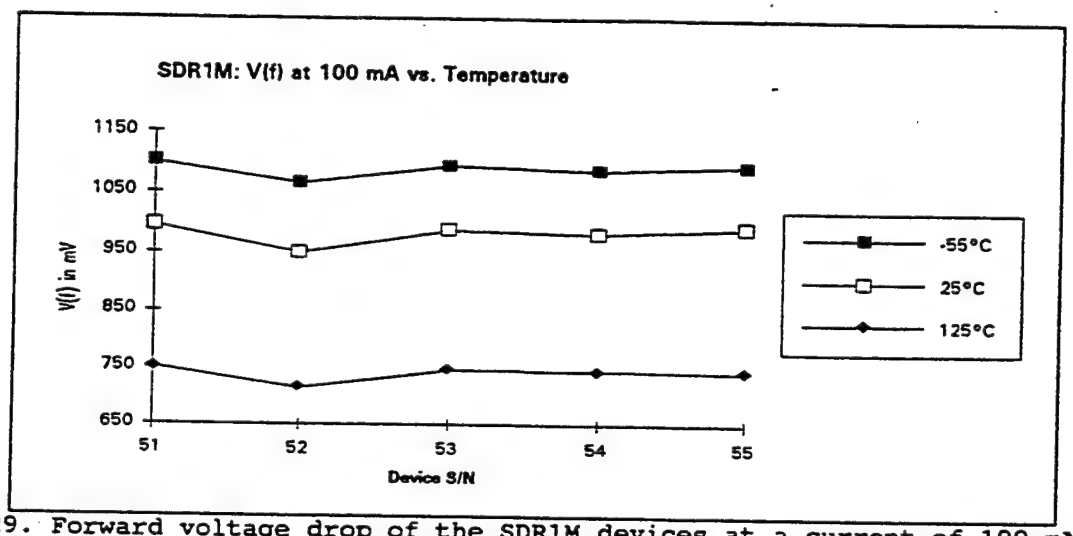

Figure V29. Forward voltage drop of the SDR1M devices at a current of 100 mA plotted for three temperatures. Again, the devices have fairly uniform behavior for all three temperatures.

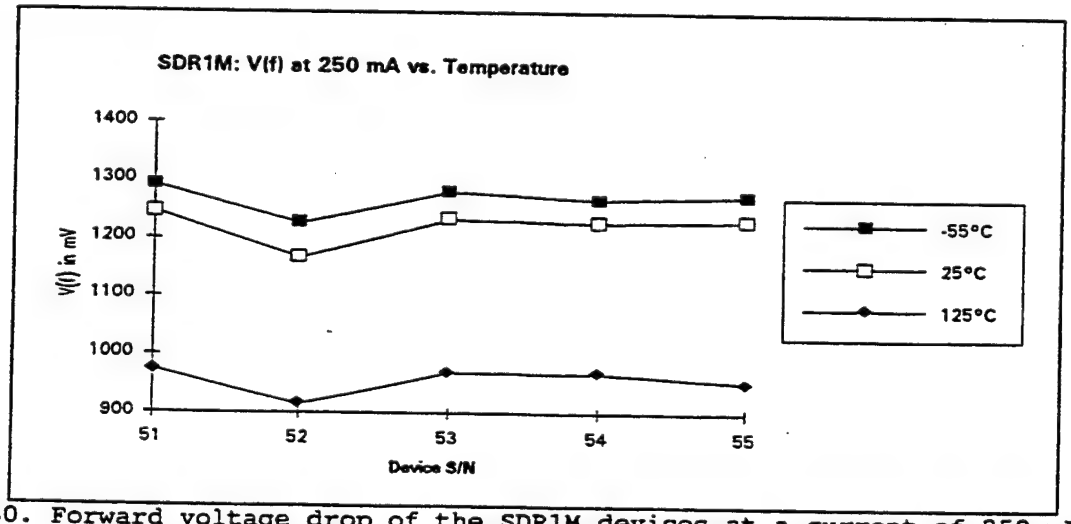

Figure V30. Forward voltage drop of the SDR1M devices at a current of 250 mA plotted for three temperatures. Again, the devices have fairly uniform behavior at all three temperatures (Device S/N 52 is lower but by less than 100 mV). Variation with temperature is different for this current.

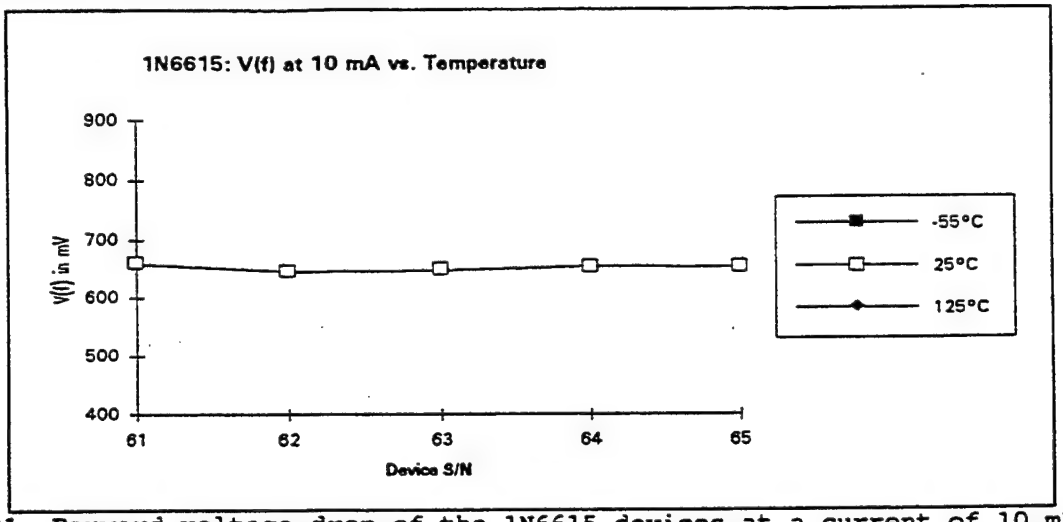

Figure V31. Forward voltage drop of the 1N6615 devices at a current of 10 mA plotted for 25°C only. (-55°C and 125°C values were not available.) The devices have fairly uniform behavior.

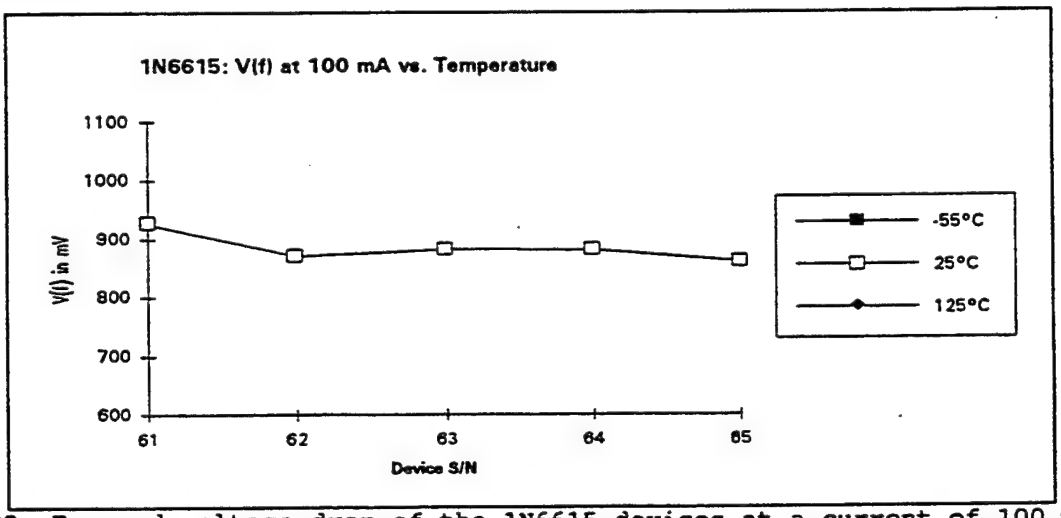

Figure V32. Forward voltage drop of the 1N6615 devices at a current of 100 mA plotted for 25°C only. (-55°C and 125°C values were not available.) The devices have fairly uniform behavior.

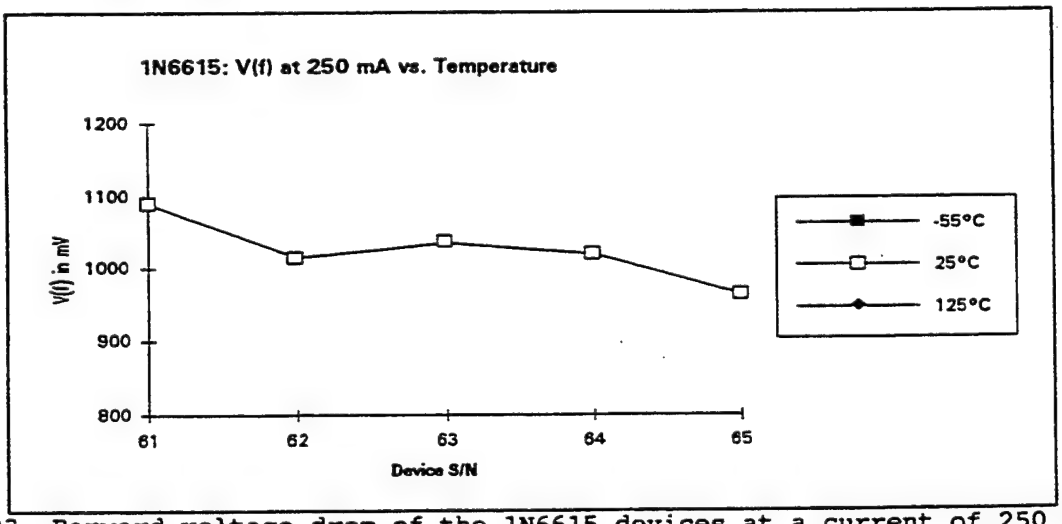

Figure V33. Forward voltage drop of the 1N6615 devices at a current of 250 mA plotted for 25°C only. (-55°C and 125°C values were not available.) There is considerable differences in the values from device to device.

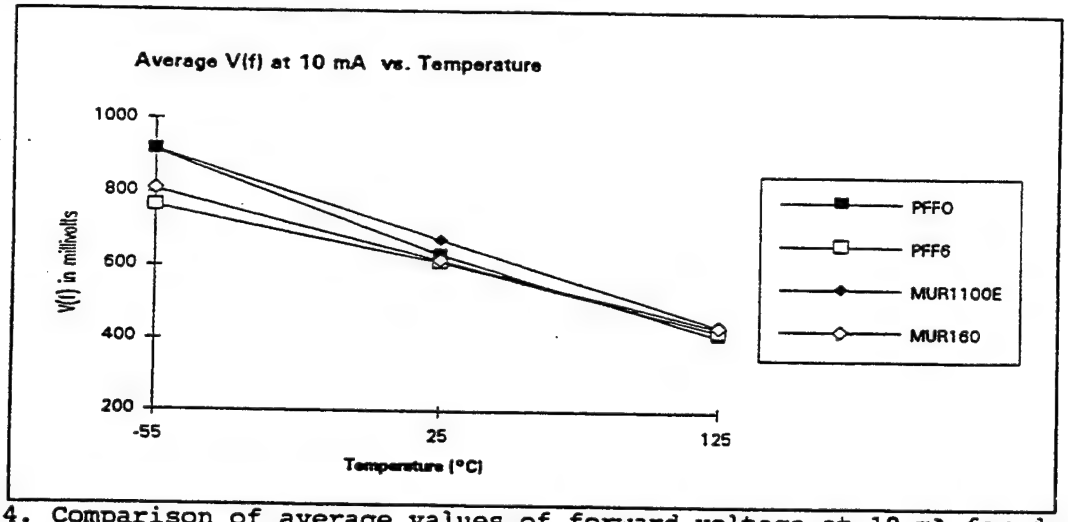

Figure V34. Comparison of average values of forward voltage at 10 mA for device types PFFO, PFF6, MUR1100E and MUR160. They are all similar for the three temperatures.

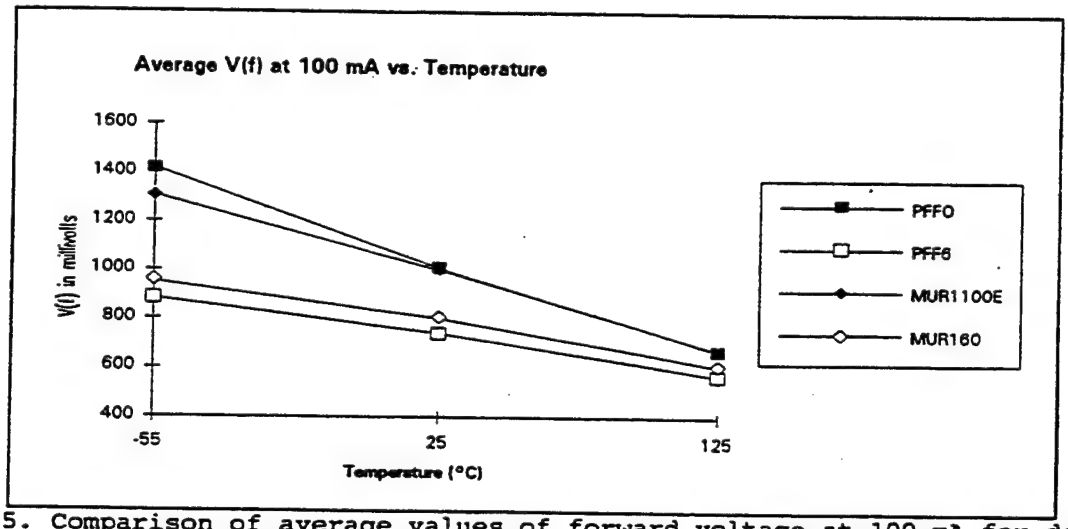

Figure V35. Comparison of average values of forward voltage at 100 mA for device types PFFO, PFF6, MUR1100E and MUR160. The PFFO and MUR1100 devices have higher values especially at lower temperatures.

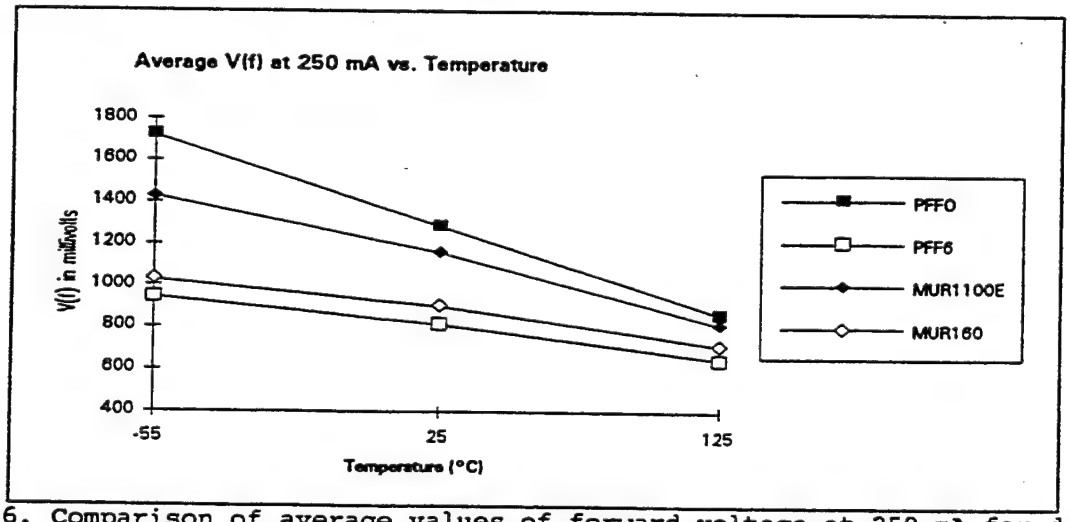

Figure V36. Comparison of average values of forward voltage at 250 mA for device types PFFO, PFF6, MUR1100E and MUR160. The PFFO and MUR1100 devices have higher values especially at lower temperatures.

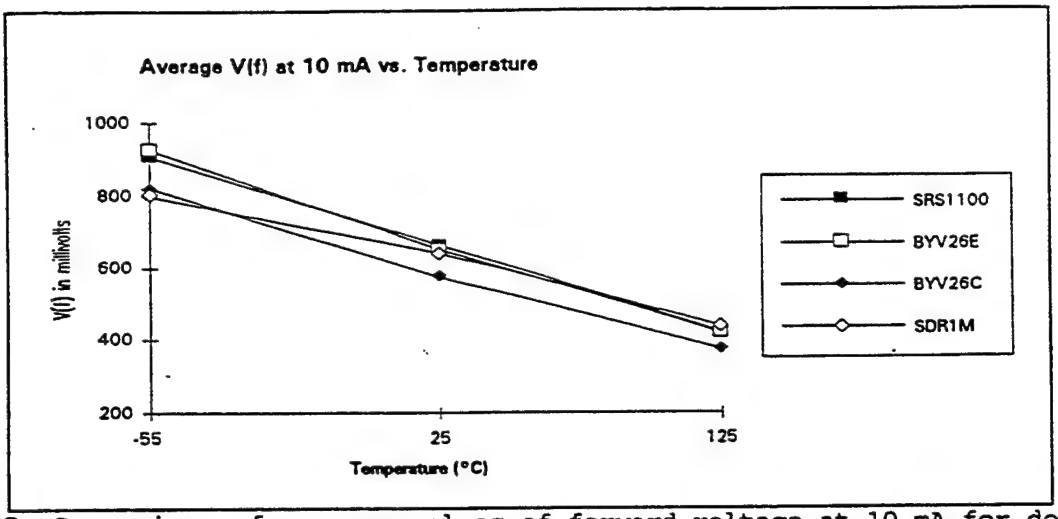

Figure V37. Comparison of average values of forward voltage at 10 mA for device types SRS1100, BYV26E, BYV26C and SDR1M. They are all similar for the three temperatures.

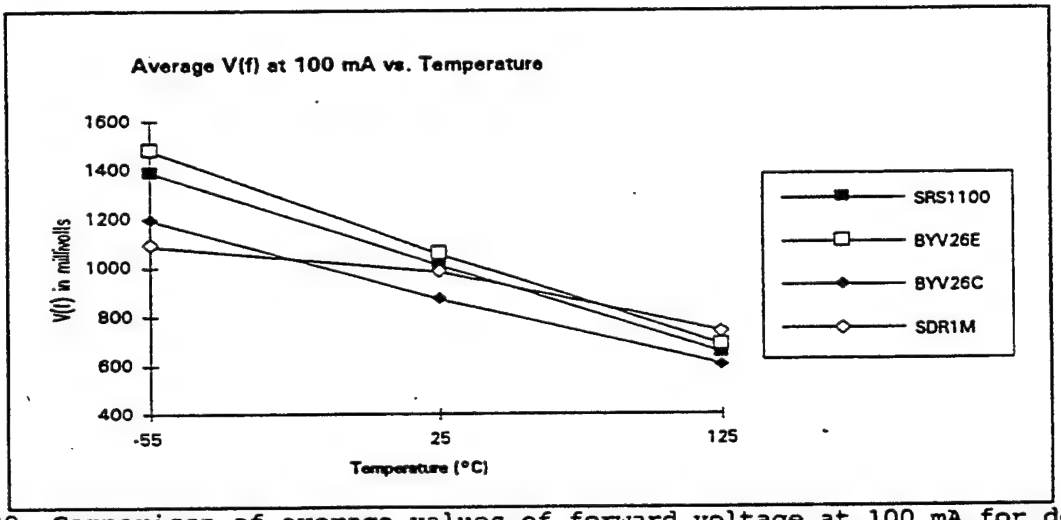

Figure V38. Comparison of average values of forward voltage at 100 mA for device types SRS1100, BYV26E, BYV26C and SDR1M. The BYV26E and SRS1100 values are higher especially at lower temperatures.

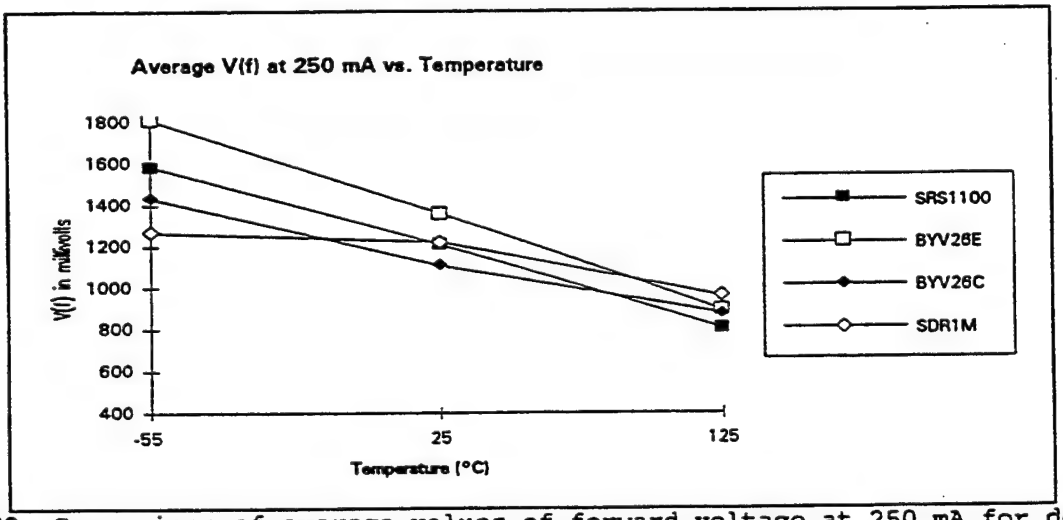

Figure V39. Comparison of average values of forward voltage at 250 mA for device types SRS1100, BYV26E, BYV26C and SDR1M. Again, the BYV26E and SRS1100 values are higher especially at lower temperatures.

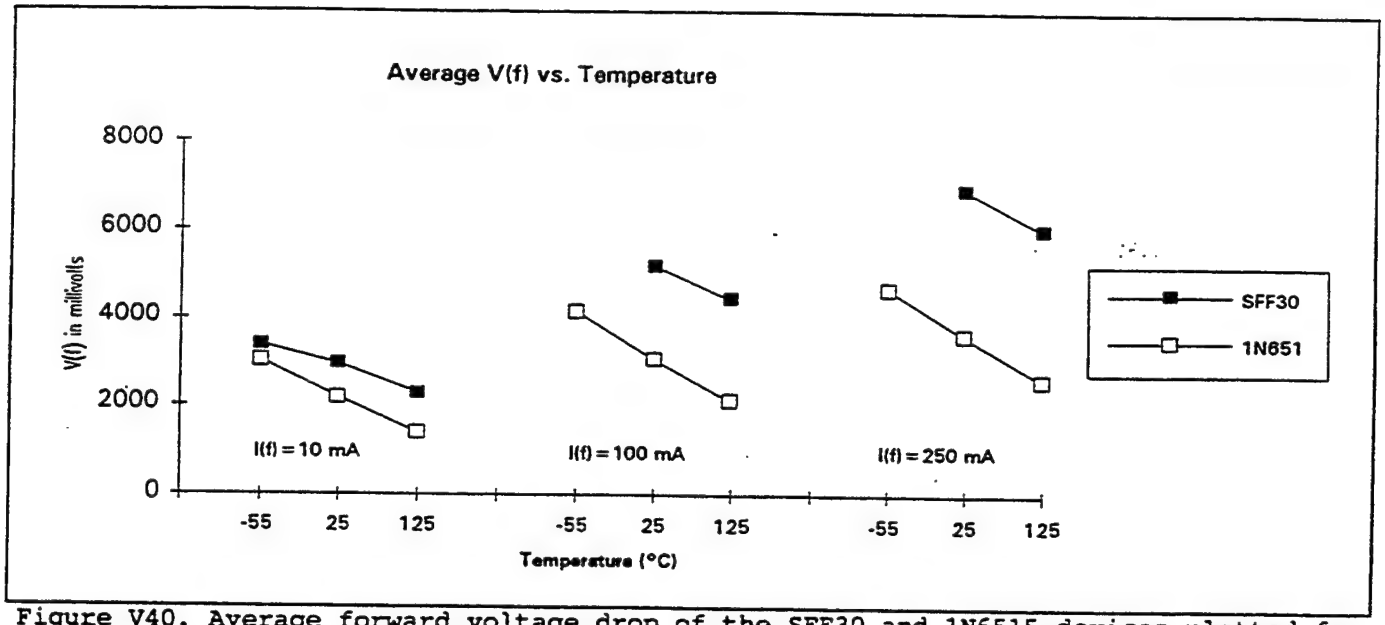

Figure V40. Average forward voltage drop of the SFF30 and 1N6515 devices plotted for three temperatures. The voltage drops at 10 mA are plotted in the left group, at 100 mA in the center group and at 250 mA in the right group. V(f) measurements at 100 and 250 mA at -55°C were not available for the SFF30 devices.

These devices were plotted separately from the other devices since they had much higher V(f) values at all currents and temperatures. Note that the high current values of V(f) for the SFF30 devices are much higher than the 1N6515 devices.

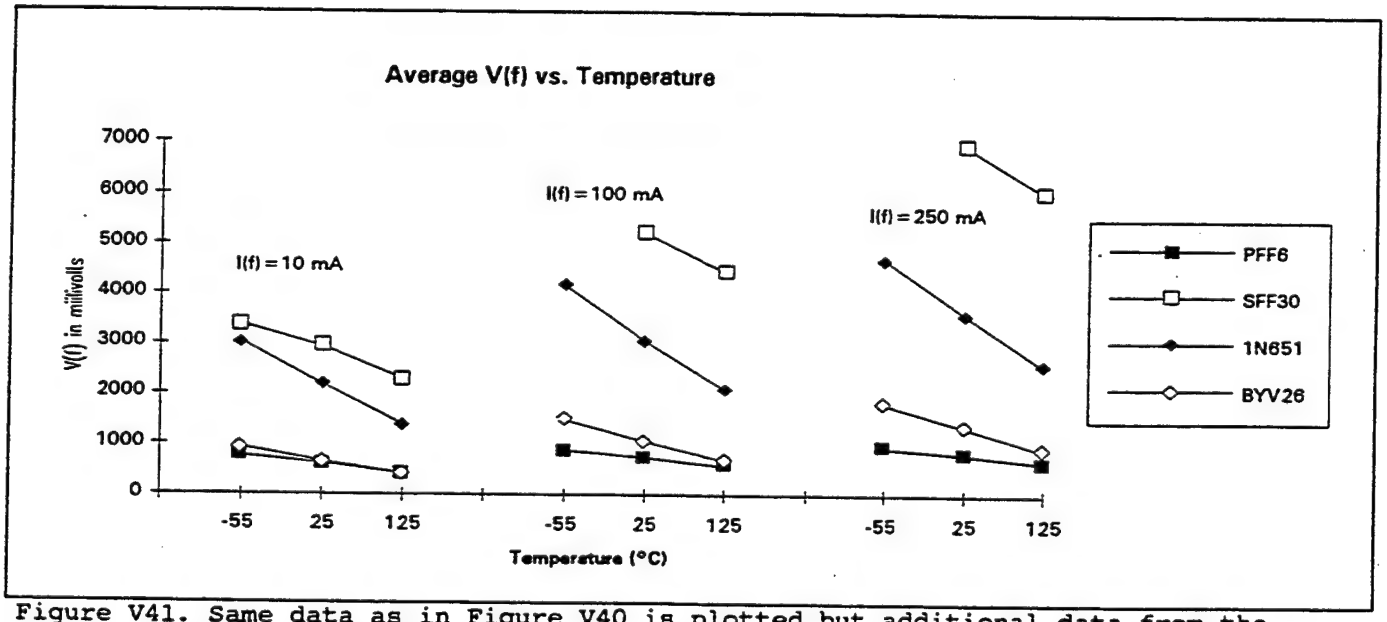

Figure V41. Same data as in Figure V40 is plotted but additional data from the diodes with lower forward voltage drops is added. The voltage drops from devices PFF6 and BYV26E are added to this chart. Of the devices with relatively low V(f) values, these devices had the lowest and highest values of V(f).

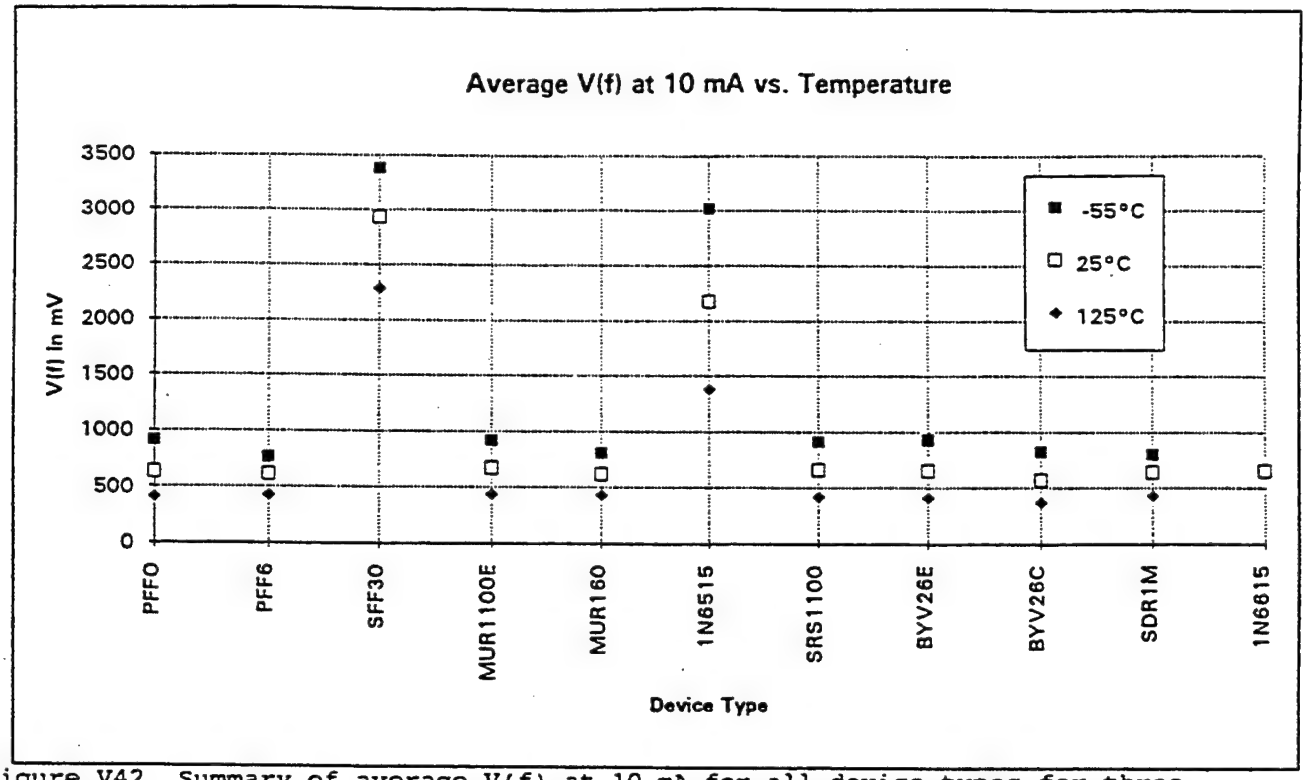

Figure V42. Summary of average V(f) at 10 mA for all device types for three temperatures. (Some device types did not have values for all temperatures.)

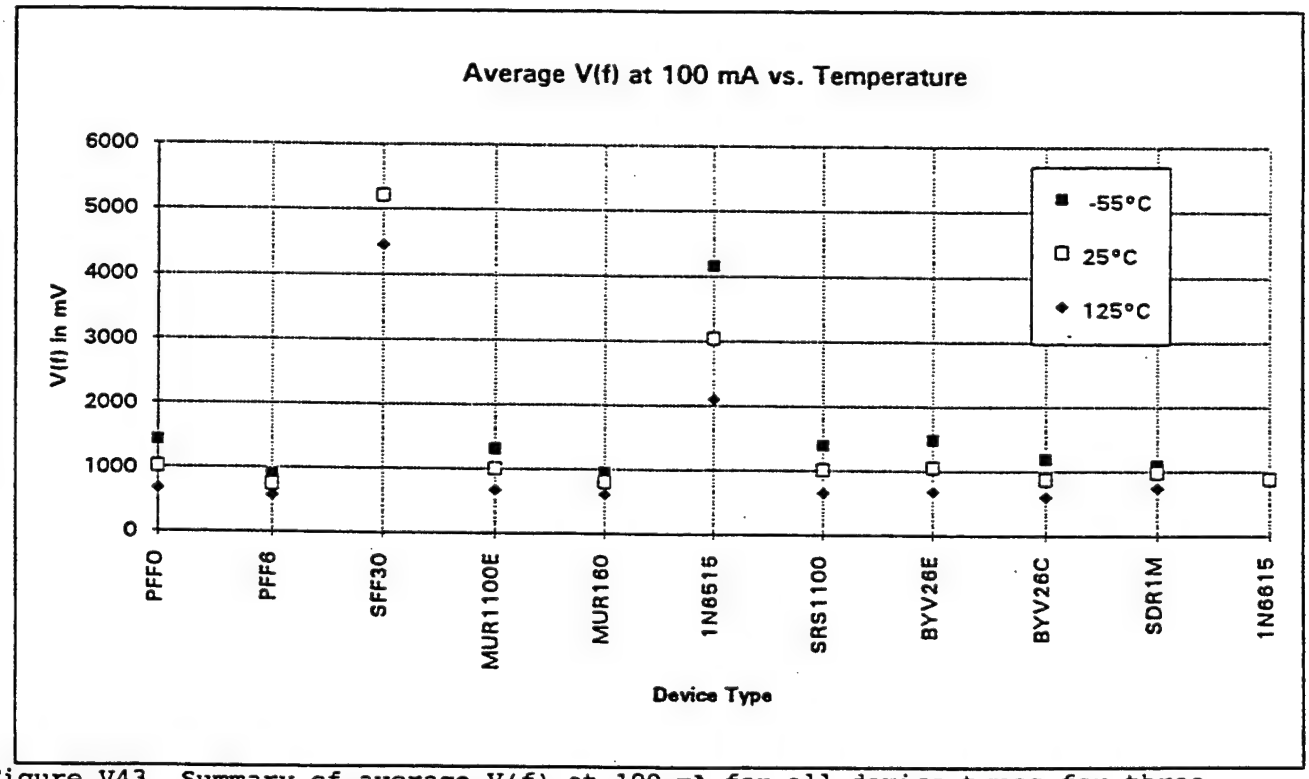

Figure V43. Summary of average V(f) at 100 mA for all device types for three temperatures. (Some device types did not have values for all temperatures.)

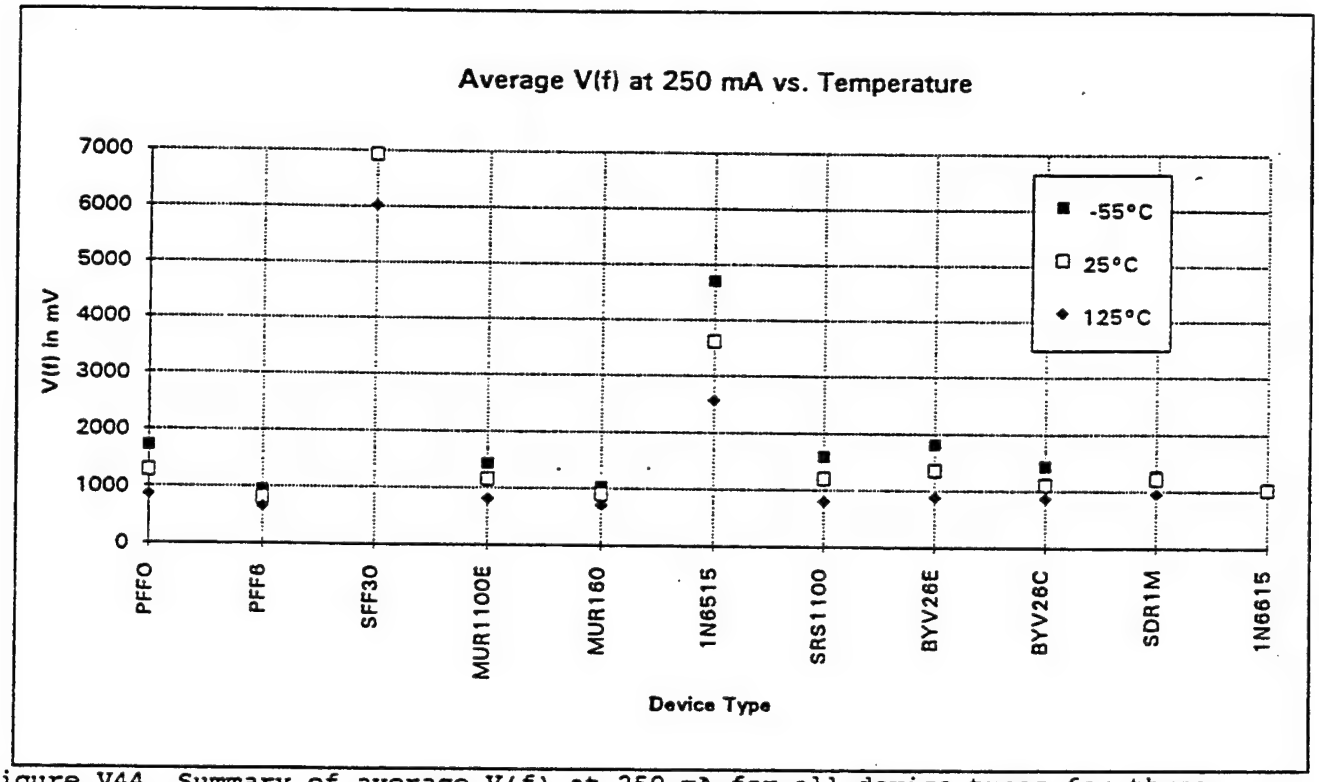

Figure V44. Summary of average V(f) at 250 mA for all device types for three temperatures. (Some device types did not have values for all temperatures.)

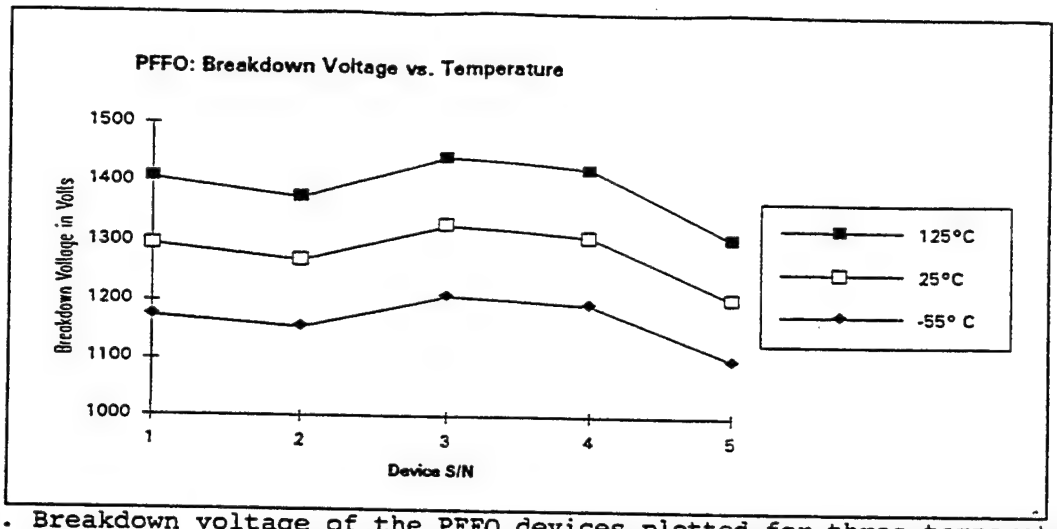

Figure B1. Breakdown voltage of the PFFO devices plotted for three temperatures. Some variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

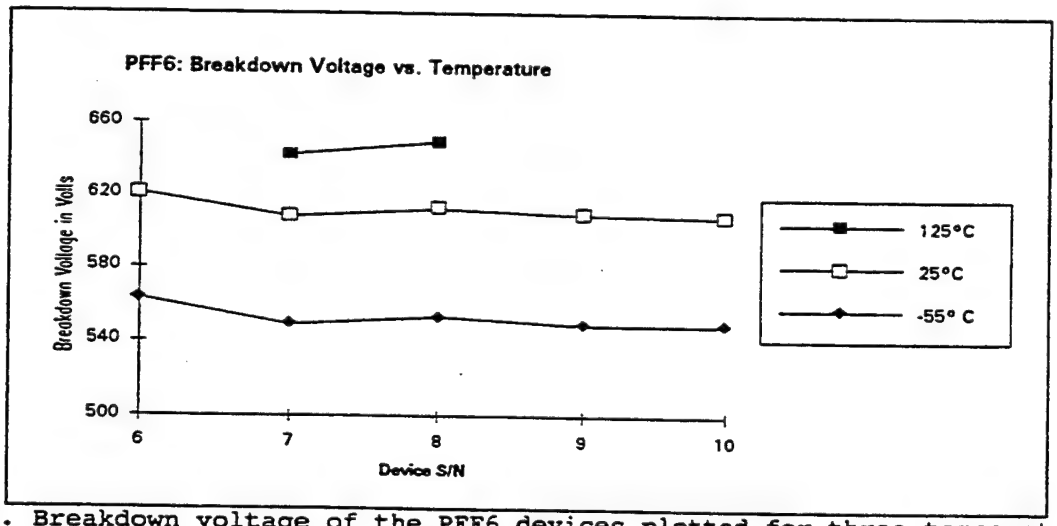

Figure B2. Breakdown voltage of the PFF6 devices plotted for three temperatures. Only small variations are seen from device to device. Variation with temperature is fairly consistent from device to device (125° data was not available for S/N 6,9,10)

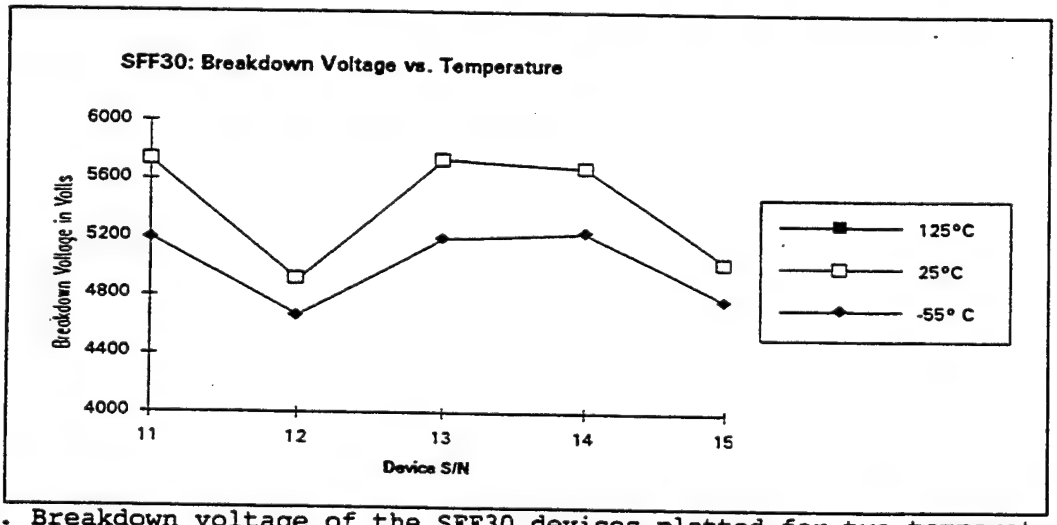

Figure B3. Breakdown voltage of the SFF30 devices plotted for two temperatures. Large variations are seen from device to device. Variation with temperature is fairly consistent from device to device (125° data was not measured to avoid overstressing the devices).

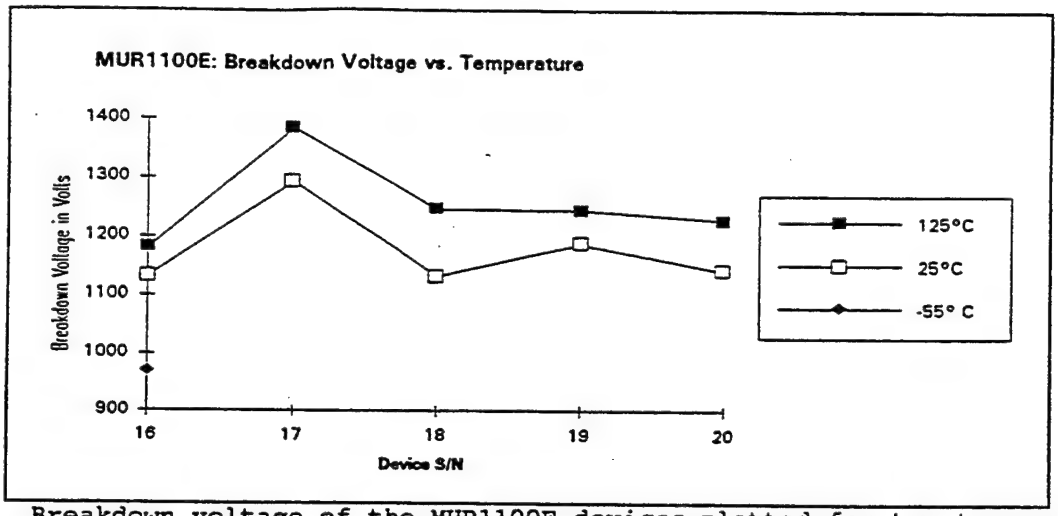

Figure B4. Breakdown voltage of the MUR1100E devices plotted for two temperatures. Large variations are seen from device to device. Variation with temperature is fairly consistent from device to device (-55°C data was not available).

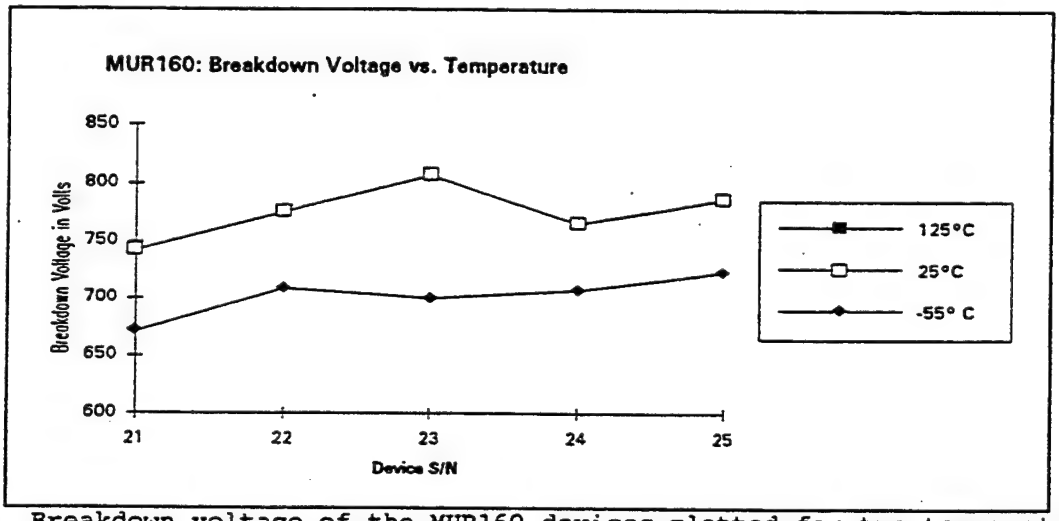

Figure B5. Breakdown voltage of the MUR160 devices plotted for two temperatures. Only small variations are seen from device to device. Variation with temperature is fairly consistent from device to device (125° data was not available).

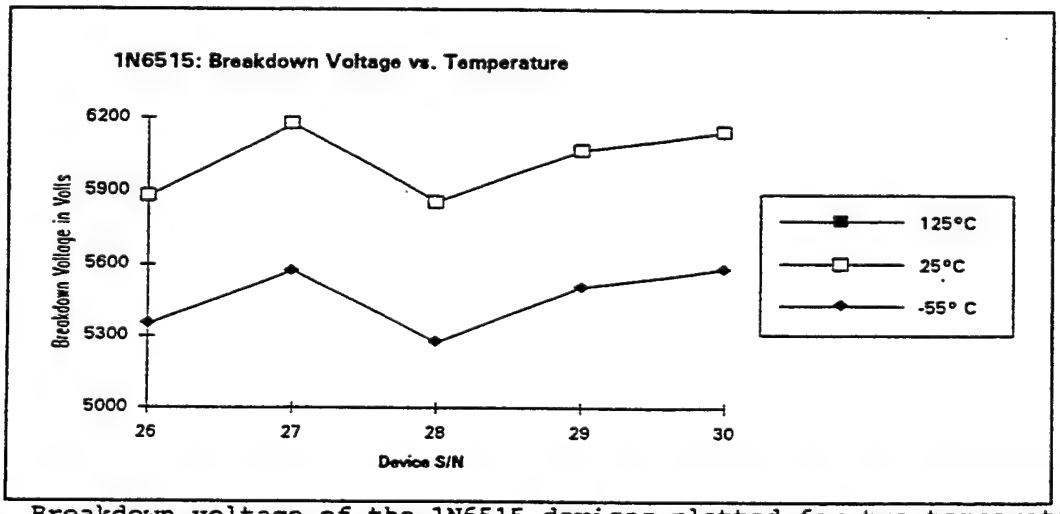

Figure B6. Breakdown voltage of the 1N6515 devices plotted for two temperatures. Some variation is seen from device to device. Variation with temperature is fairly consistent from device to device (125° data was not taken to avoid overstressing the devices).

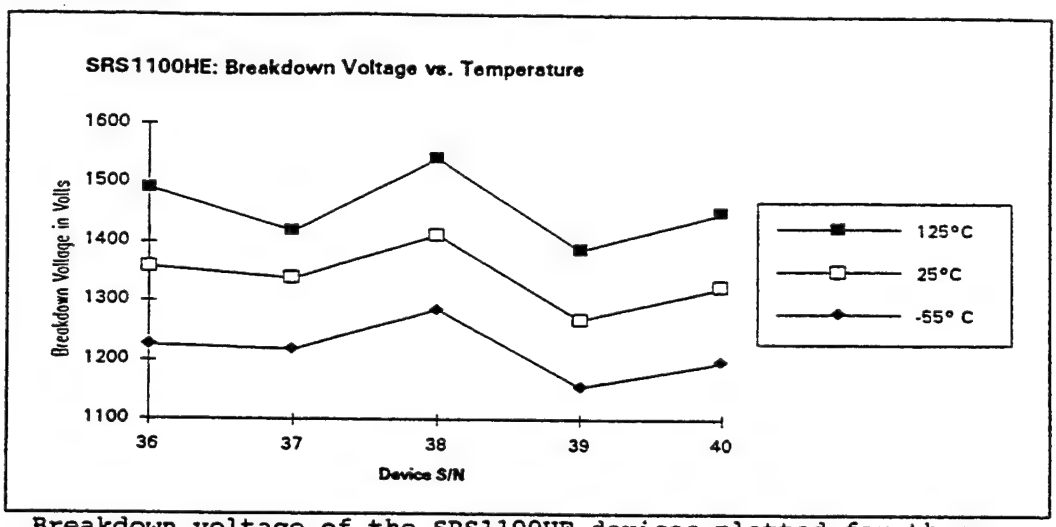

Figure B7. Breakdown voltage of the SRS1100HE devices plotted for three temperatures. Large variations are seen from device to device. Variation with temperature is fairly consistent from device to device.

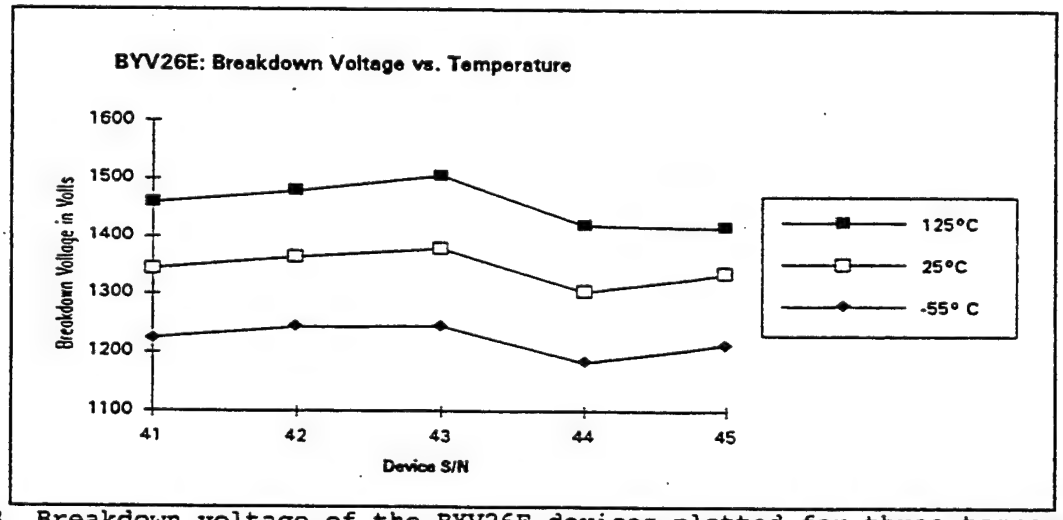

Figure B8. Breakdown voltage of the BYV26E devices plotted for three temperatures. Some variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

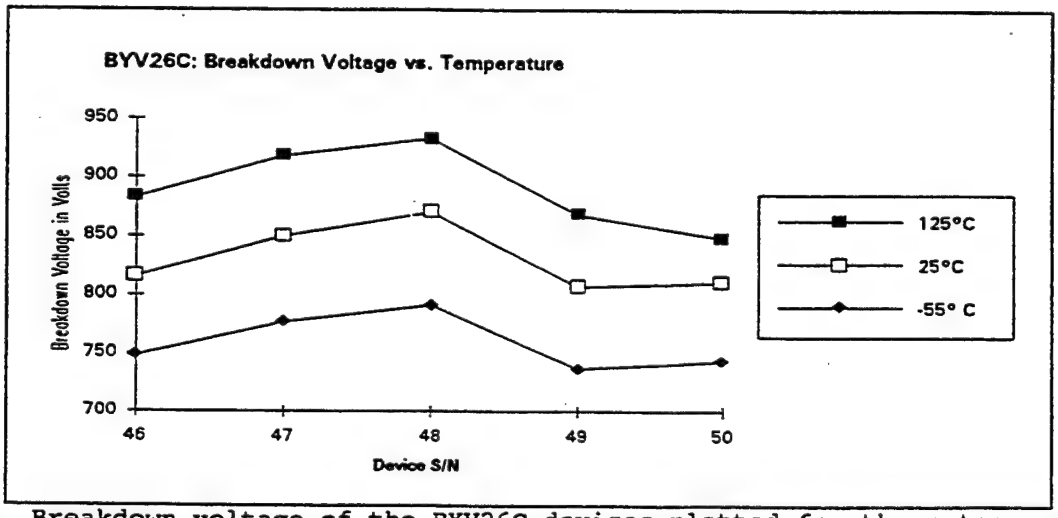

Figure B9. Breakdown voltage of the BYV26C devices plotted for three temperatures. Large variations are seen from device to device. Variation with temperature is fairly consistent from device to device.

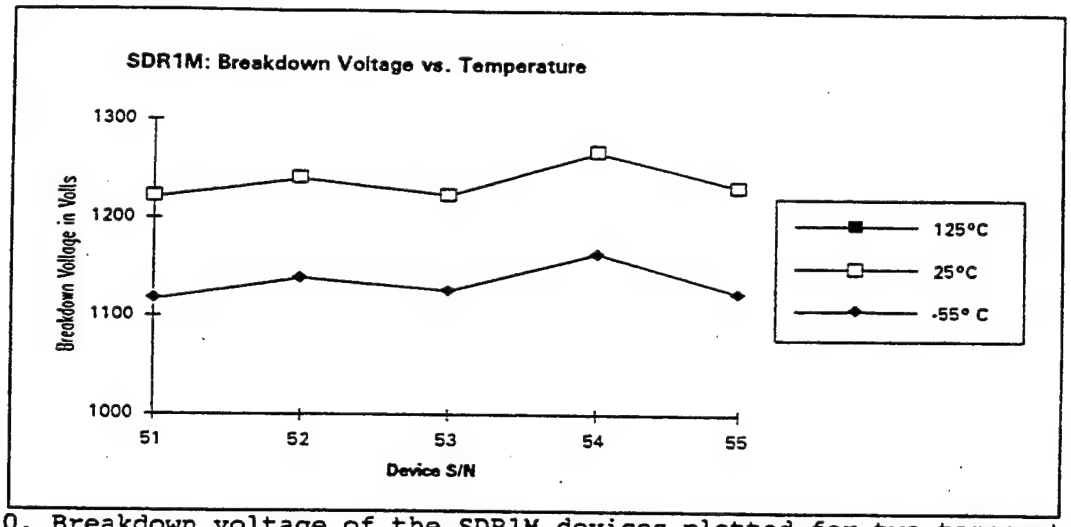

Figure B10. Breakdown voltage of the SDR1M devices plotted for two temperatures. Only small variations are seen from device to device. Variation with temperature is fairly consistent from device to device (125° data was not available).

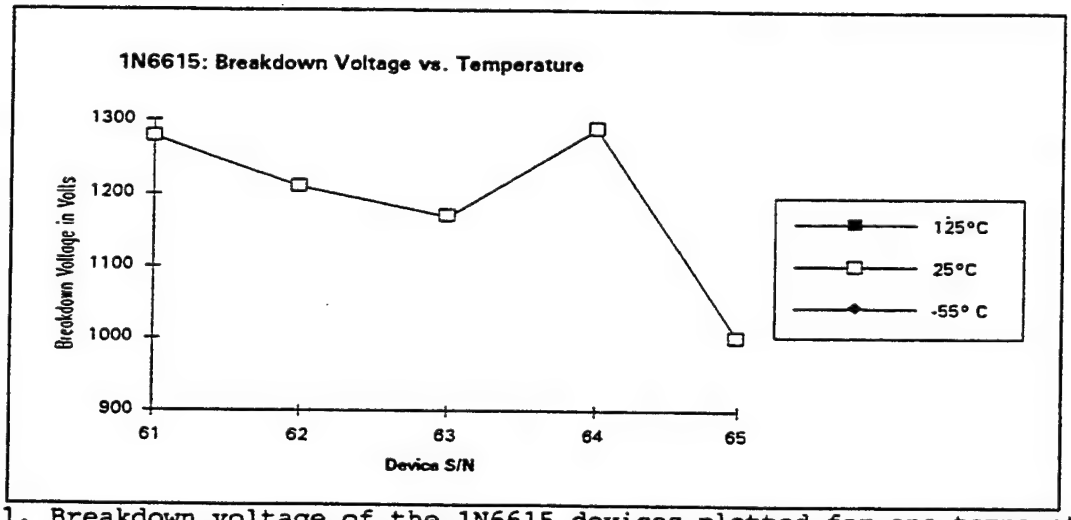

Figure B11. Breakdown voltage of the 1N6615 devices plotted for one temperature. Large variations are seen from device to device. (-55 and 125°C data was not available since the devices were overstressed during 25°C testing.)

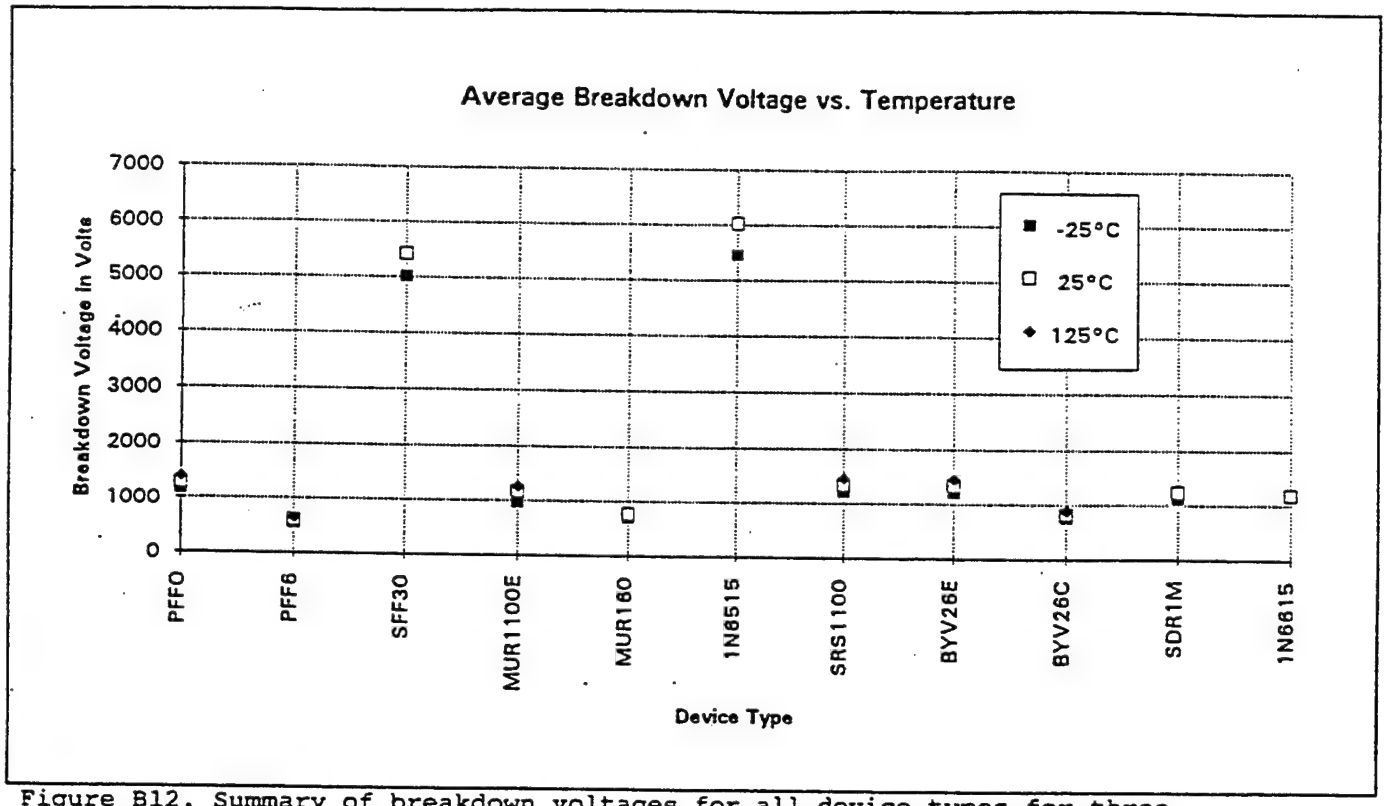

Figure B12. Summary of breakdown voltages for all device types for three temperatures (some devices did not have values for all three temperatures).

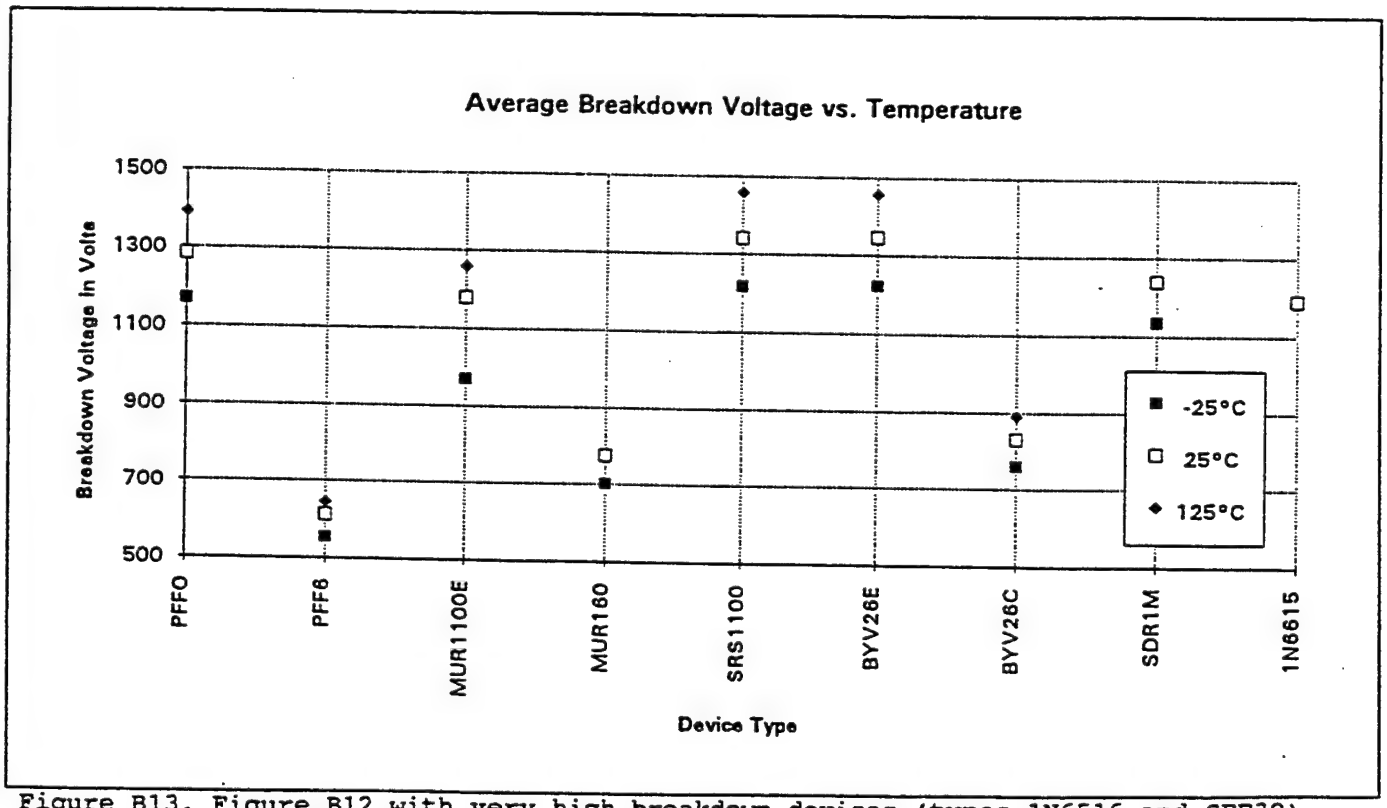

Figure B13. Figure B12 with very high breakdown devices (types 1N6516 and SFF30) removed to show more detail for other device types.

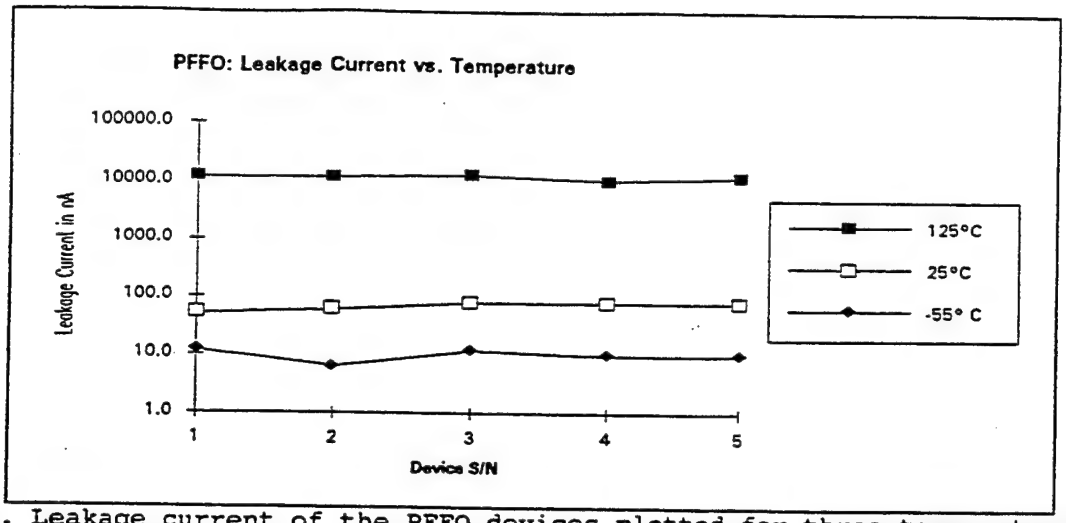

Figure L1. Leakage current of the PFFO devices plotted for three temperatures. Only minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

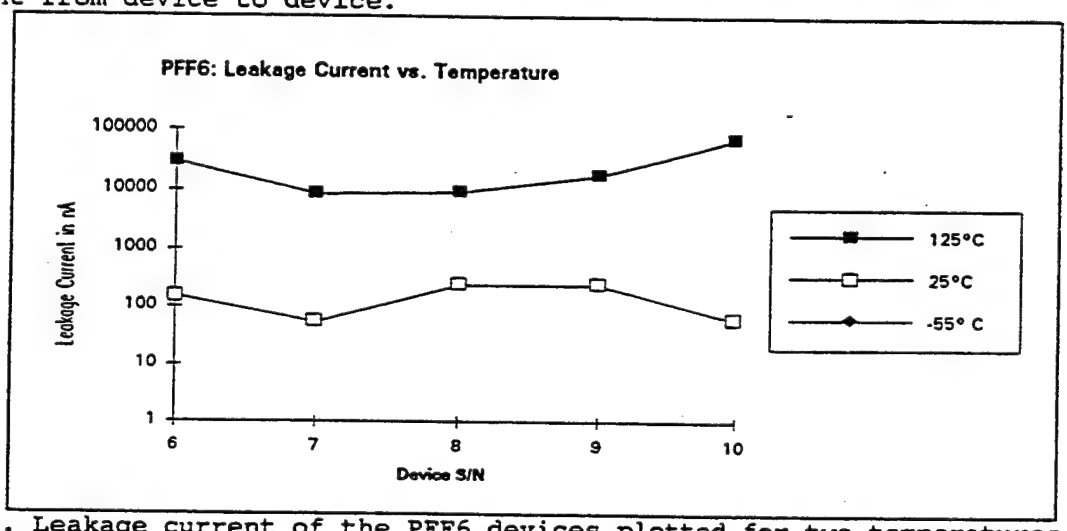

Figure L2. Leakage current of the PFF6 devices plotted for two temperatures. Considerable variation is seen from device to device. Variation with temperature is inconsistent from device to device. -55°C values were not available for this type.

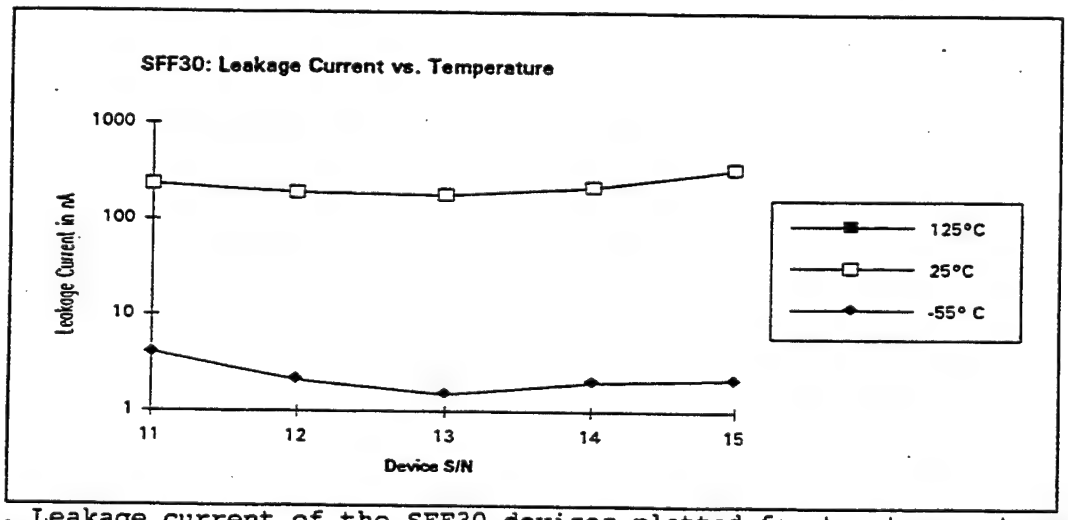

Figure L3. Leakage current of the SFF30 devices plotted for two temperatures. Only minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device. 125°C values were not available.

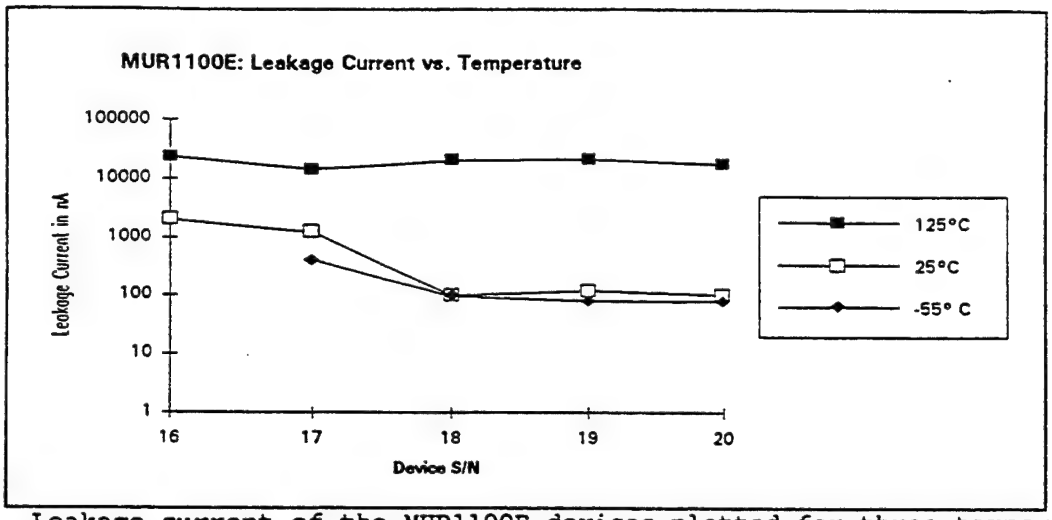

Figure L4. Leakage current of the MUR1100E devices plotted for three temperatures. Considerable variation is seen from device to device at 25°C. Variation with temperature is inconsistent from device to device. Validity of -55°C values is questionable.

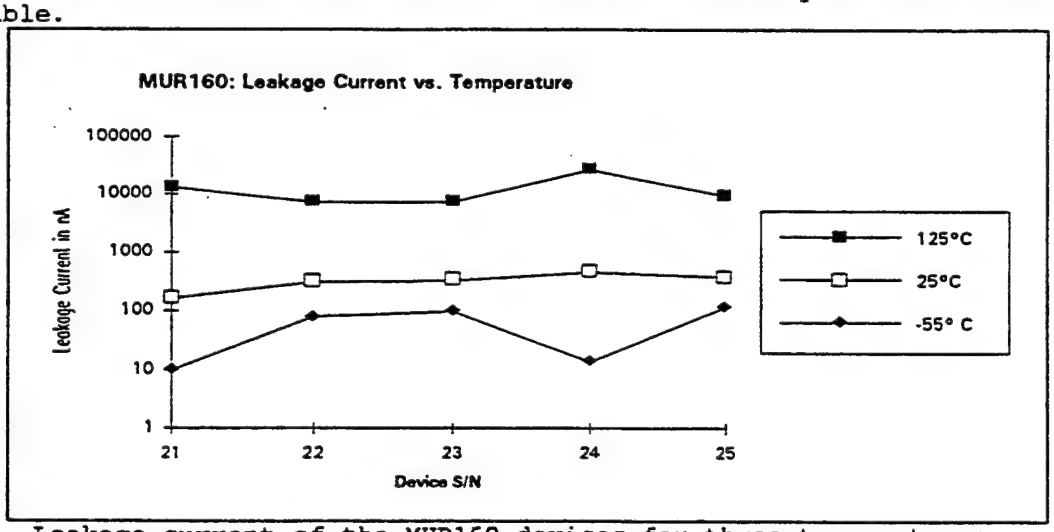

Figure L5. Leakage current of the MUR160 devices for three temperatures. Considerable variation is seen from device to device and variation with temperature is inconsistent from device to device.

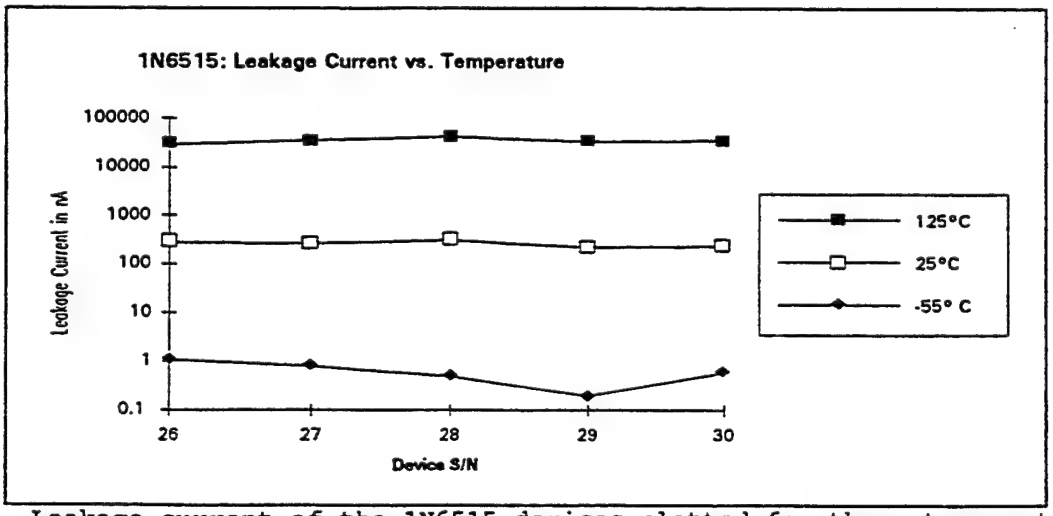

Figure L6. Leakage current of the 1N6515 devices plotted for three temperatures. Only minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

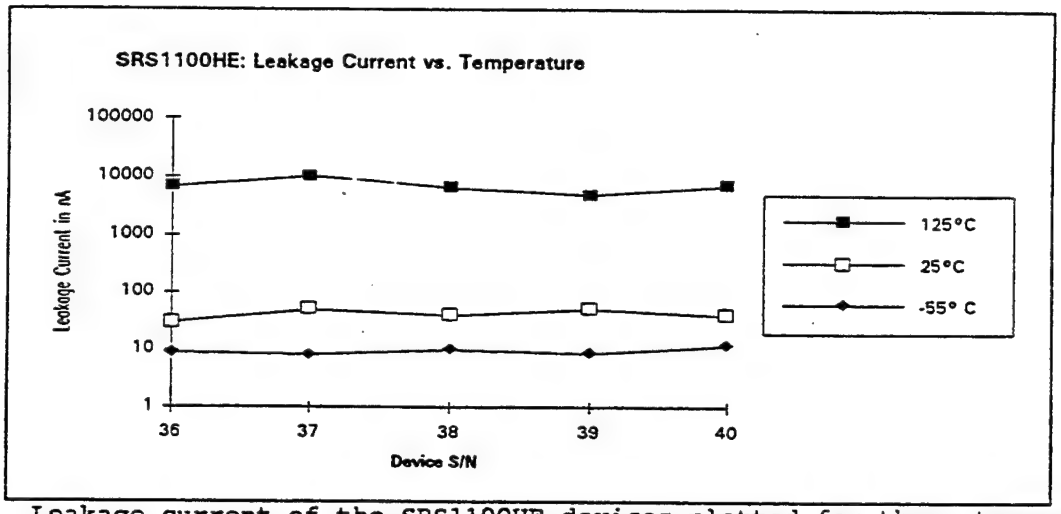

Figure L7. Leakage current of the SRS1100HE devices plotted for three temperatures. Only minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

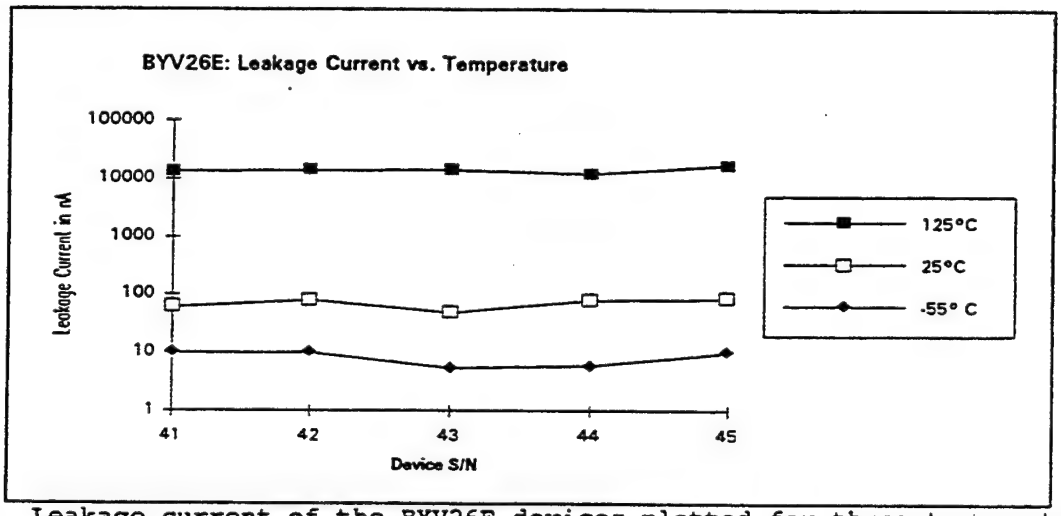

Figure L8. Leakage current of the BYV26E devices plotted for three temperatures. Only minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

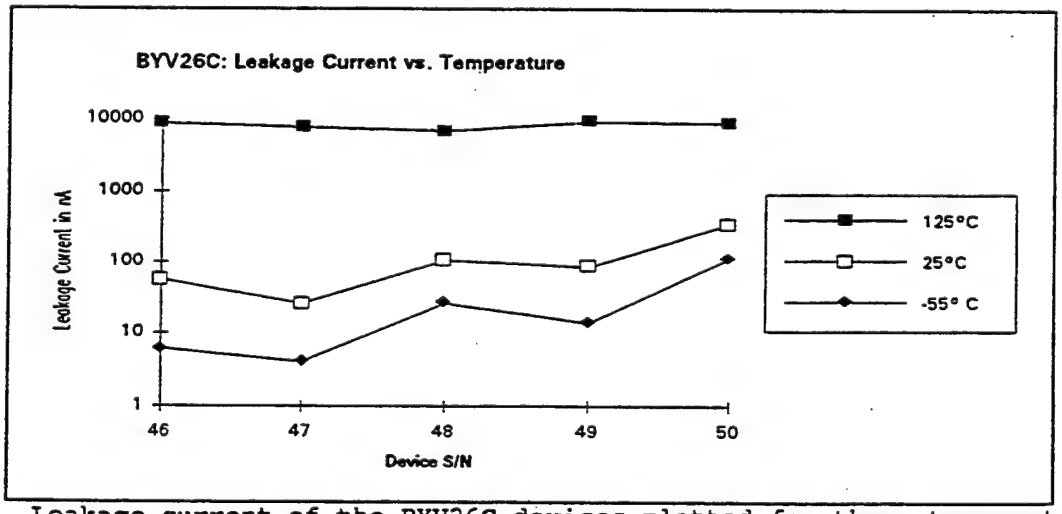

Figure L9. Leakage current of the BYV26C devices plotted for three temperatures. Considerable variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

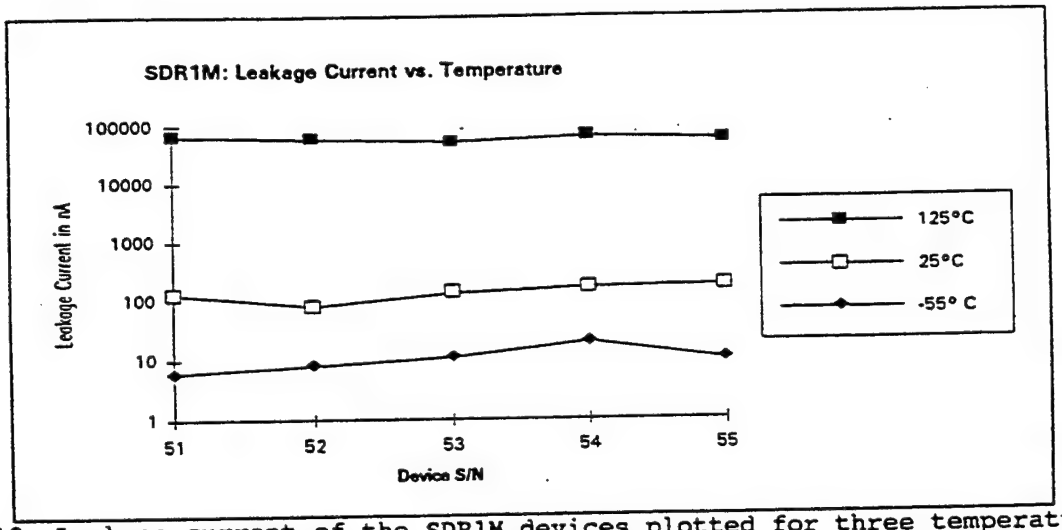

Figure L10. Leakage current of the SDR1M devices plotted for three temperatures. Only minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

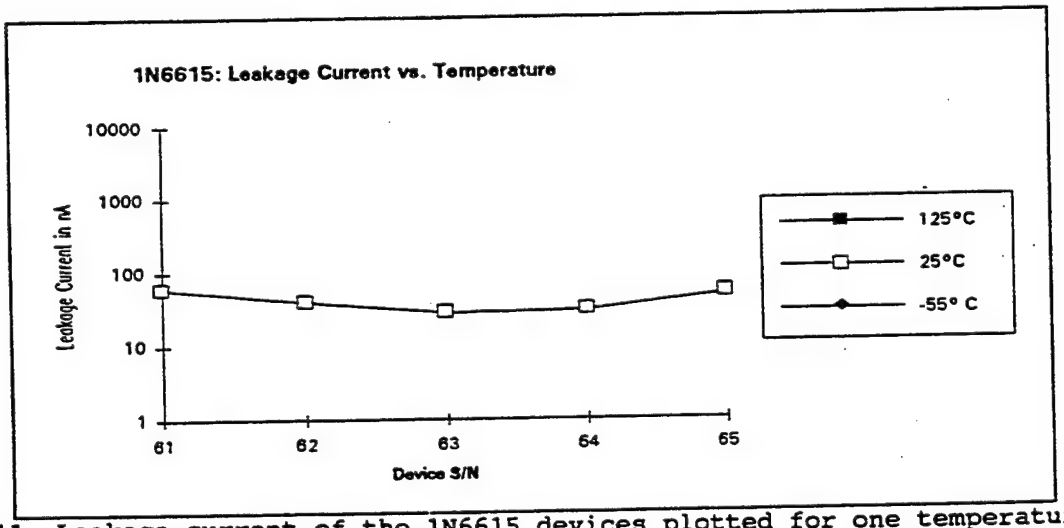

Figure L11. Leakage current of the 1N6615 devices plotted for one temperature. Leakage current is fairly consistent from device to device. (-55°C and 125°C values were not available.)

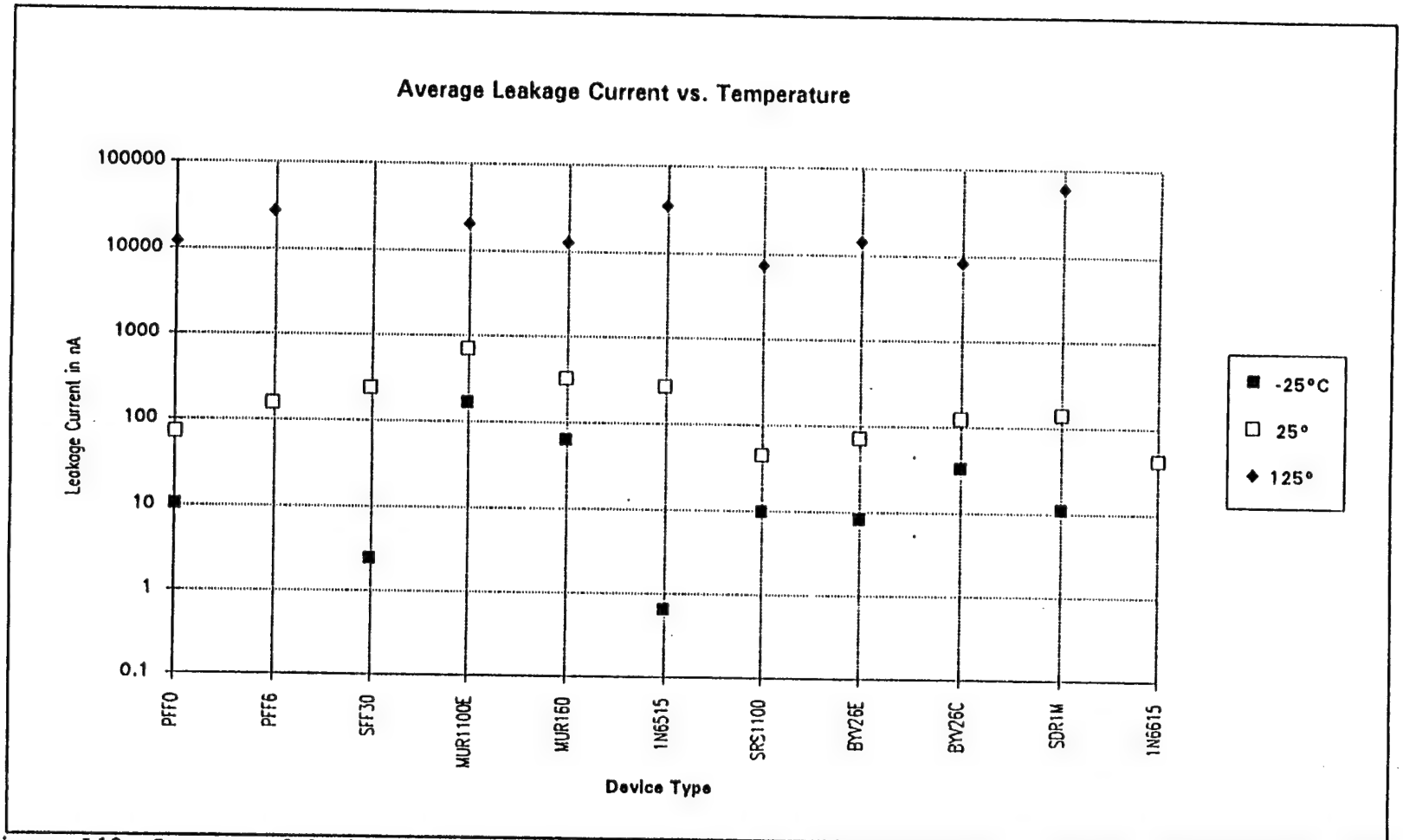

Figure L12. Summary of leakage current measurements for all device types for three temperatures (some devices did not have values for all three temperatures).

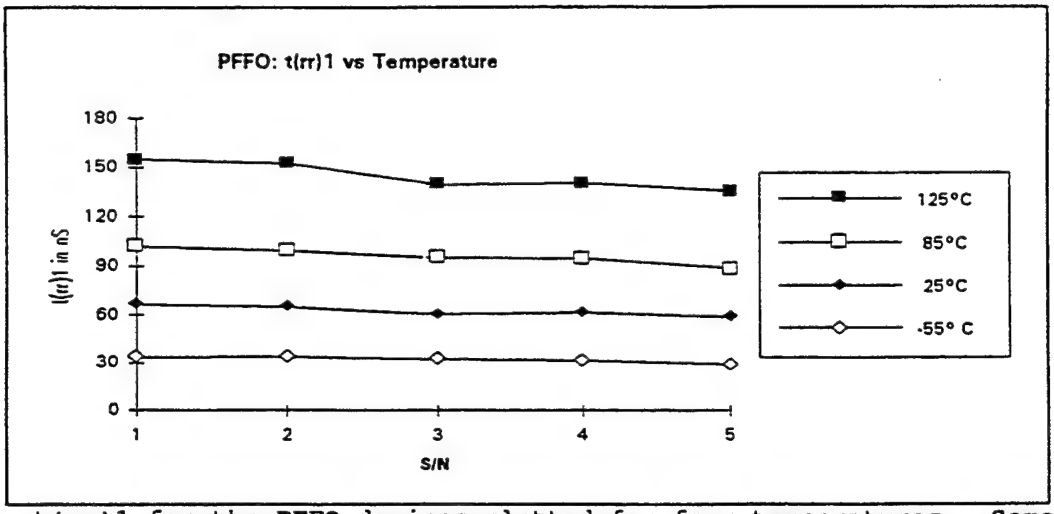

Figure T1. t(rr)1 for the PFFO devices plotted for four temperatures. Some variation is seen from device to device especially at 125°C. Variation with temperature is fairly consistent from device to device.

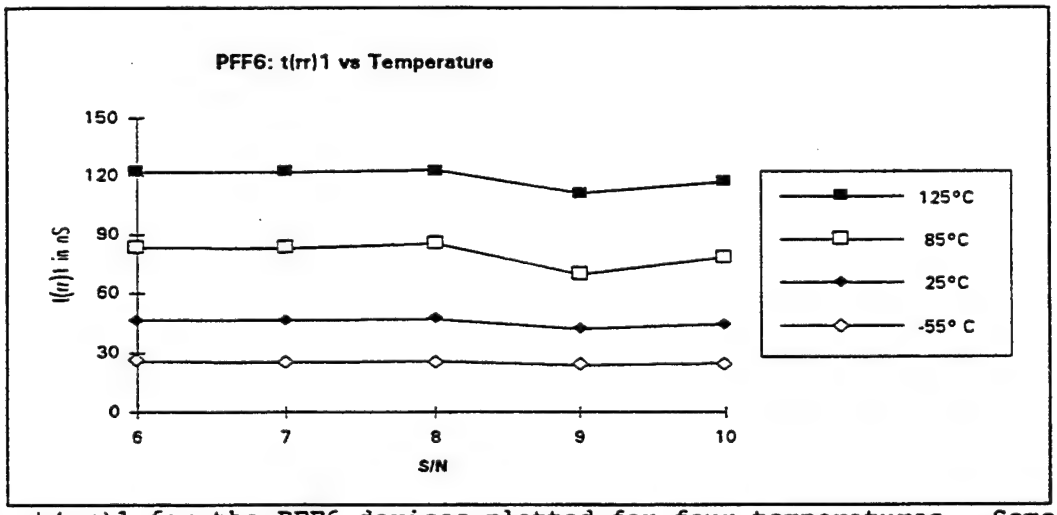

Figure T2. t(rr)1 for the PFF6 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

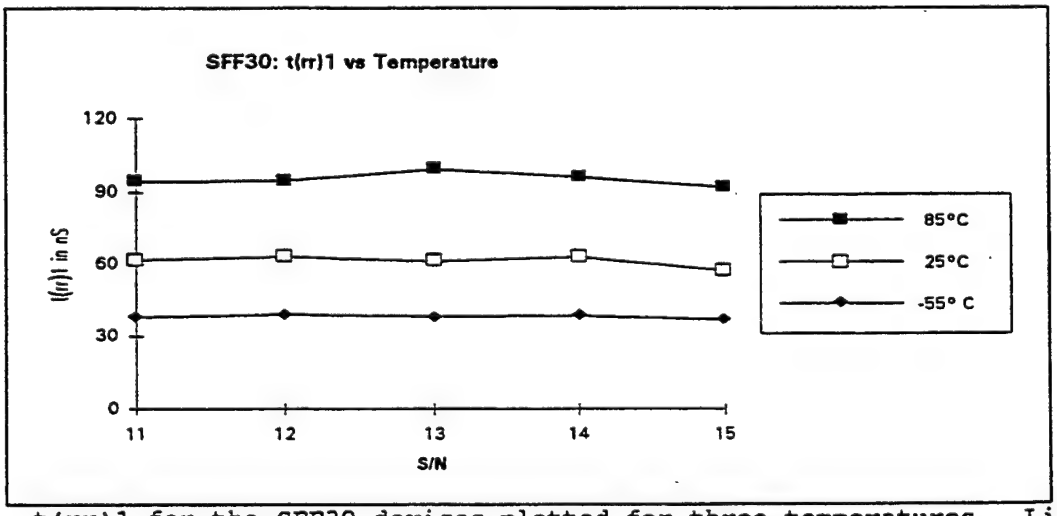

Figure T3. t(rr)1 for the SFF30 devices plotted for three temperatures. Little variation is seen from device to device. Variation with temperature is fairly consistent from device to device. (The devices were not tested at 125°C to avoid possible overstress damage.)

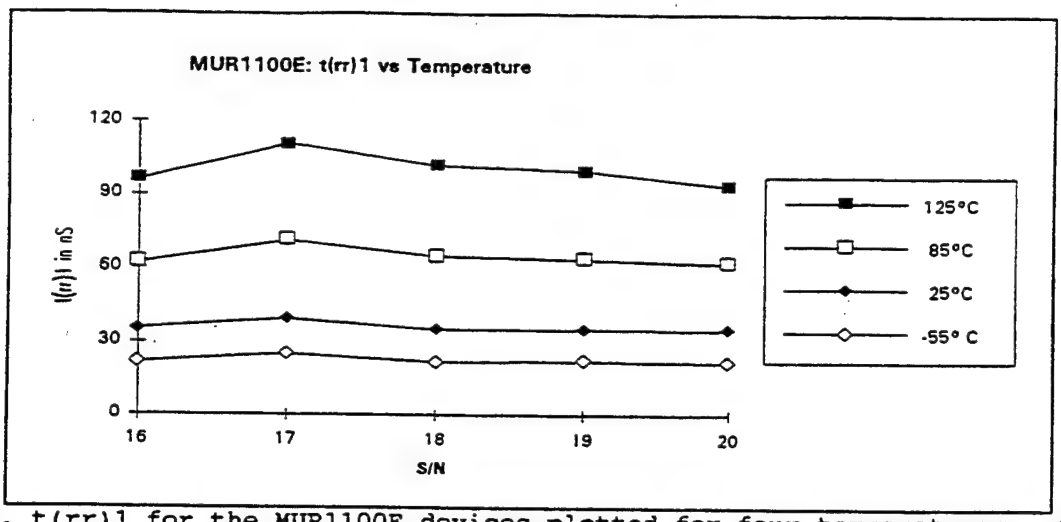

Figure T4. t(rr)1 for the MUR1100E devices plotted for four temperatures. Some variation is seen from device to device especially at 125°C. Variation with temperature is fairly consistent from device to device.

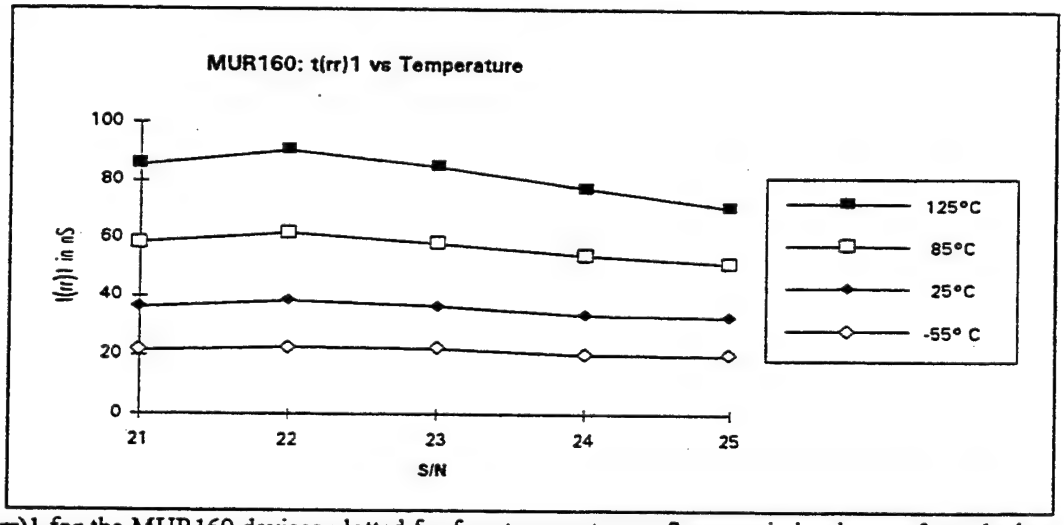

Figure T5. t(rr)1 for the MUR160 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

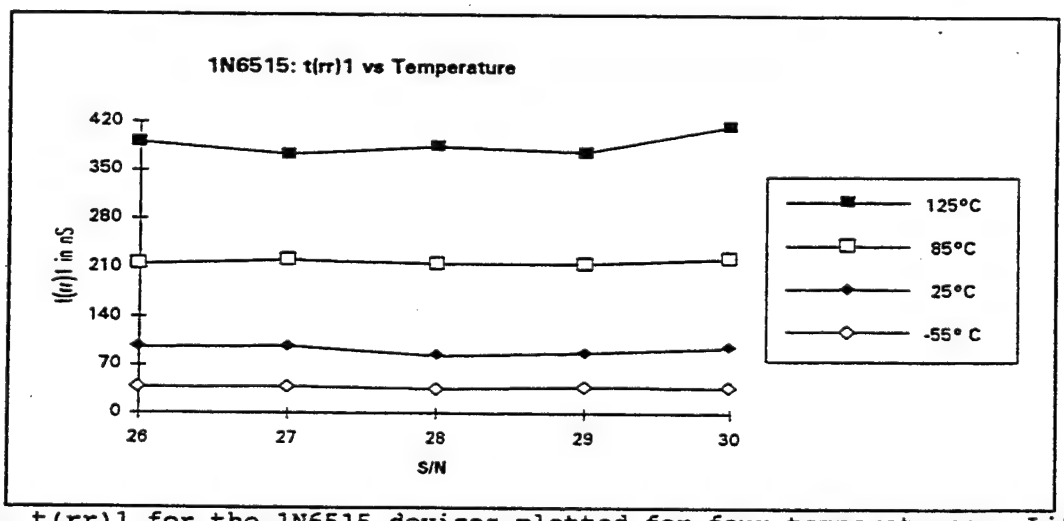

Figure T6. t(rr)1 for the 1N6515 devices plotted for four temperatures. Little variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

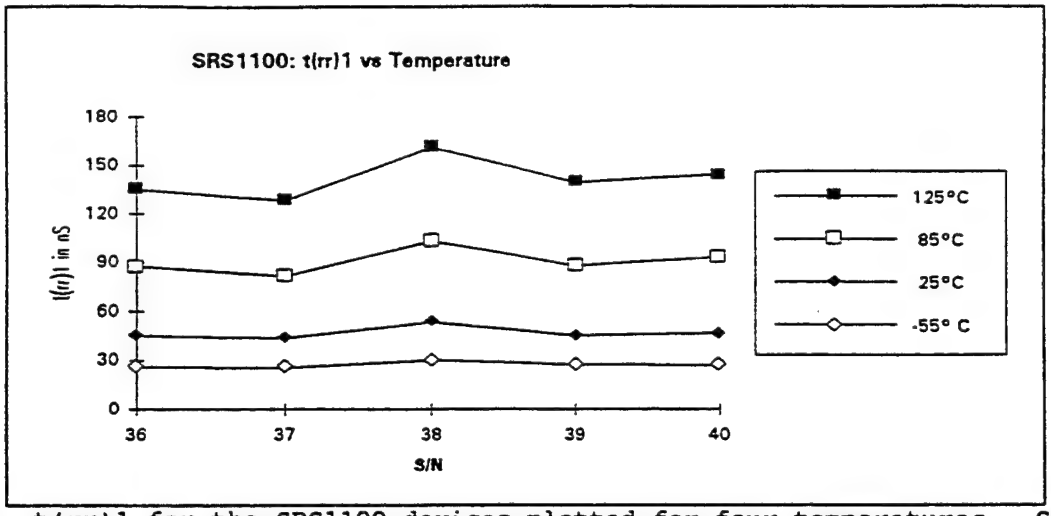

Figure T7. t(rr)1 for the SRS1100 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

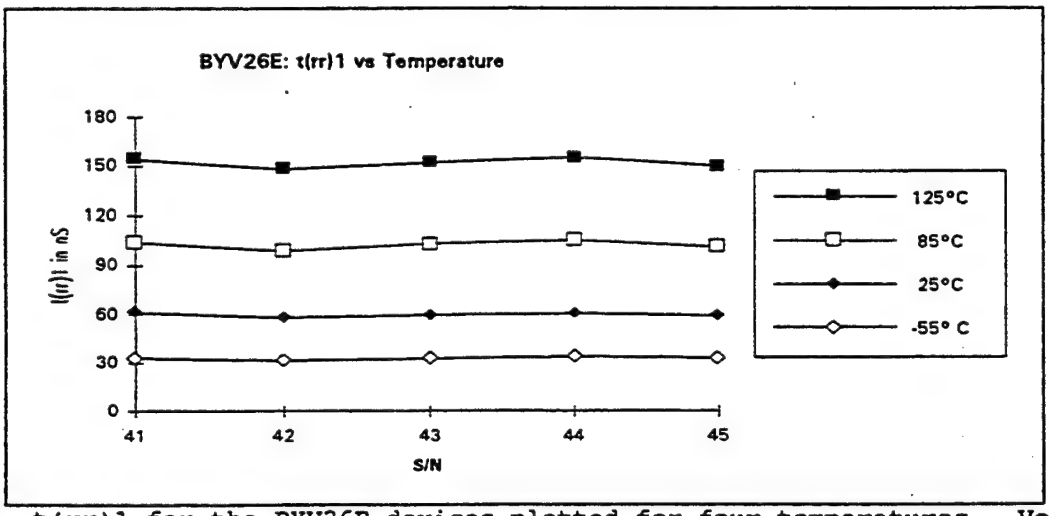

Figure T8. t(rr)1 for the BYV26E devices plotted for four temperatures. Very little variation is seen from device to device. Variation with temperature is very consistent from device to device.

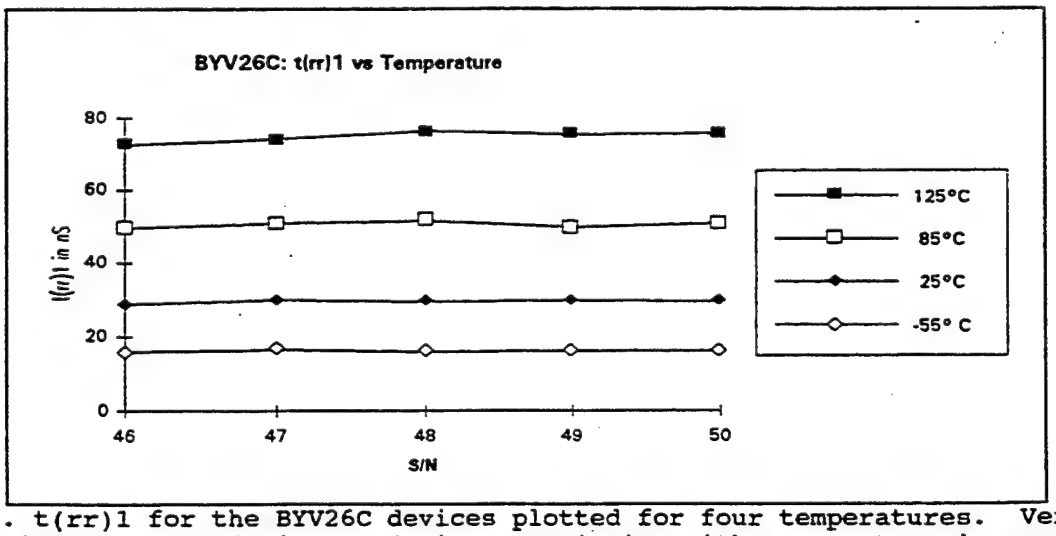

Figure T9. t(rr)1 for the BYV26C devices plotted for four temperatures. Very little variation is seen from device to device. Variation with temperature is very consistent from device to device.

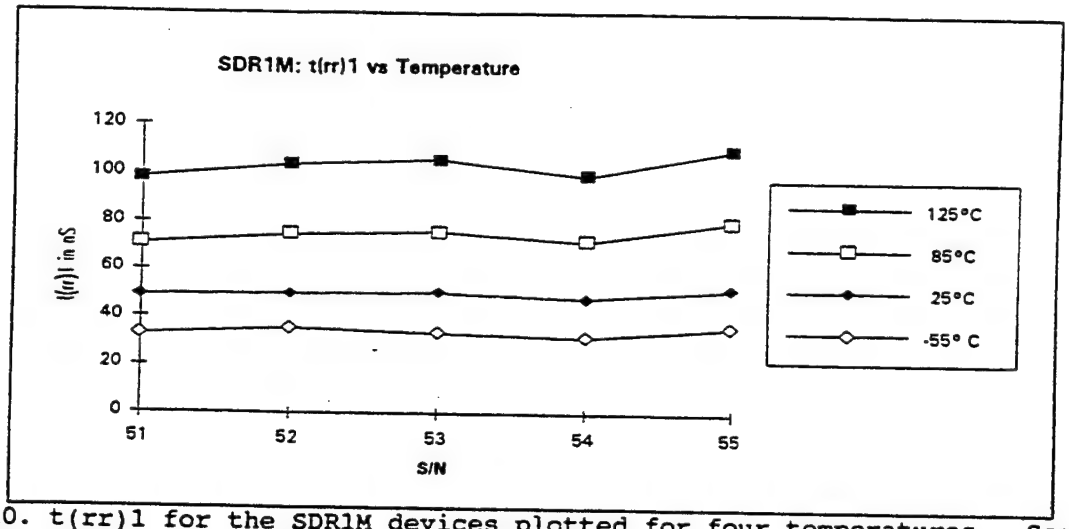

Figure T10. t(rr)1 for the SDR1M devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

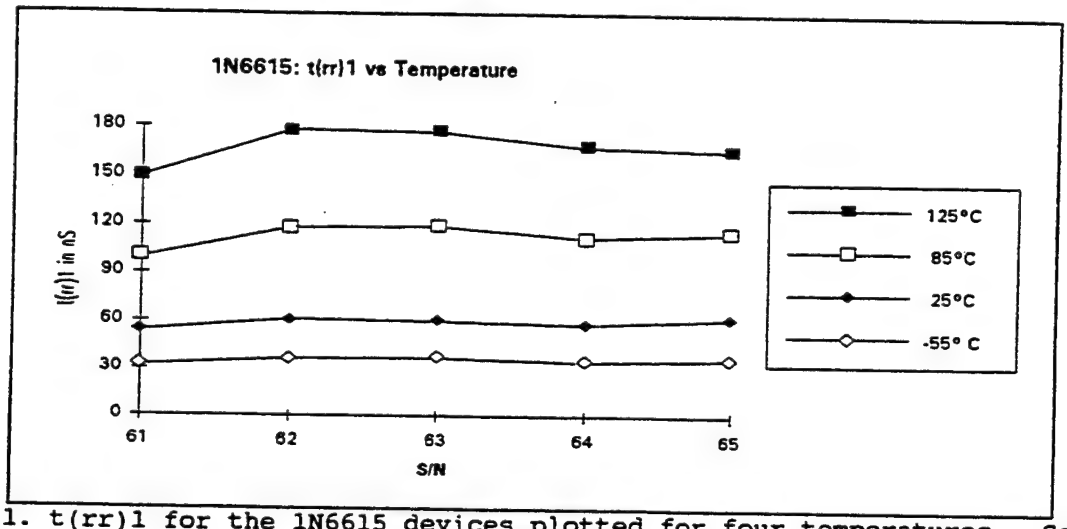

Figure T11. t(rr)1 for the 1N6615 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

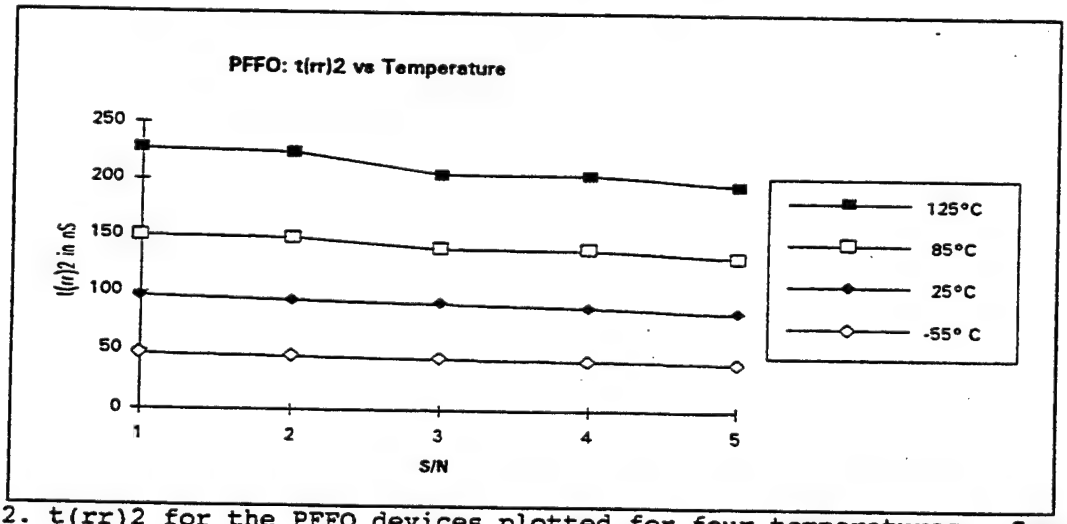

Figure T12. t(rr)2 for the PFFO devices plotted for four temperatures. Some variation is seen from device to device especially at 125°C. Variation with temperature is very consistent from device to device.

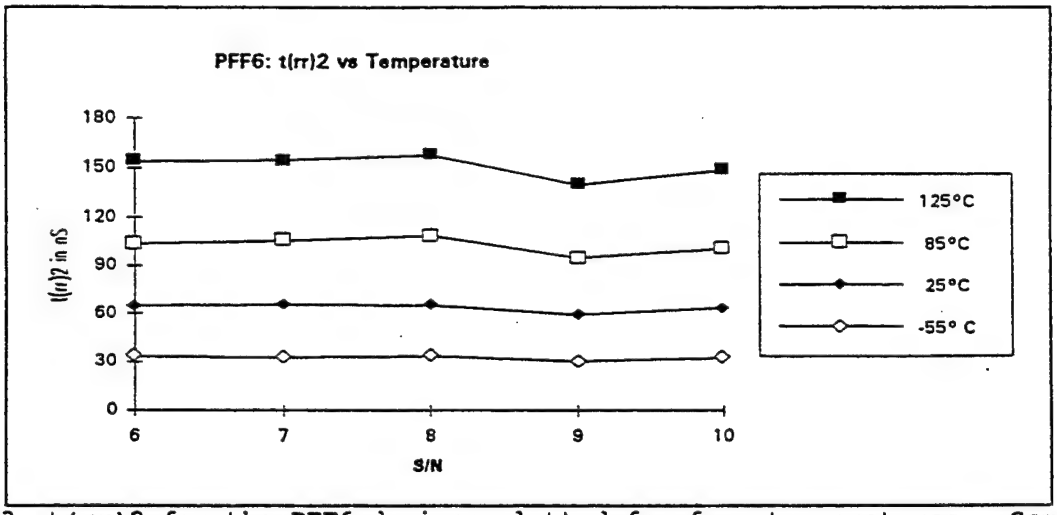

Figure T13. t(rr)2 for the PFF6 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

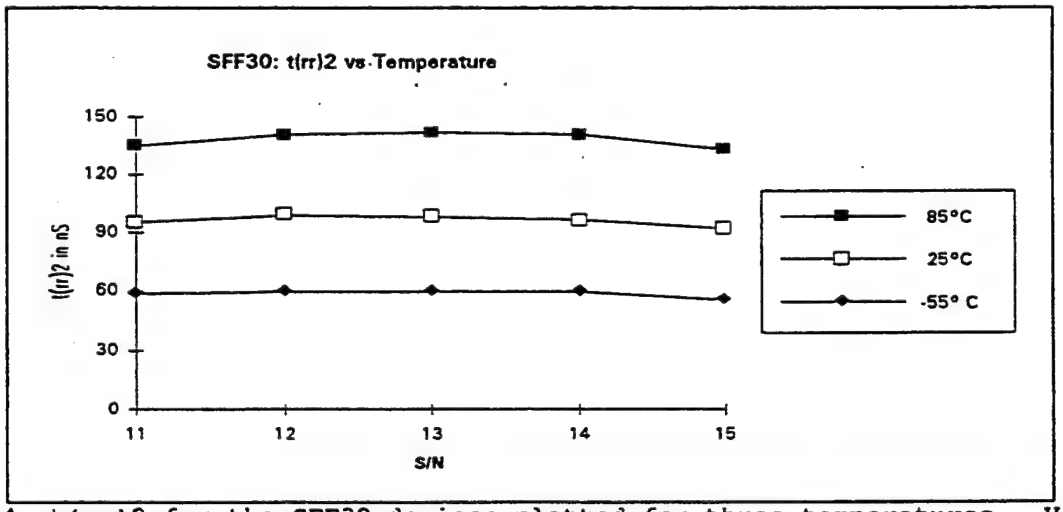

Figure T14. t(rr)2 for the SFF30 devices plotted for three temperatures. Very little variation is seen from device to device. Variation with temperature is very consistent from device to device. (The devices were not measured at 125°C to avoid overstress.)

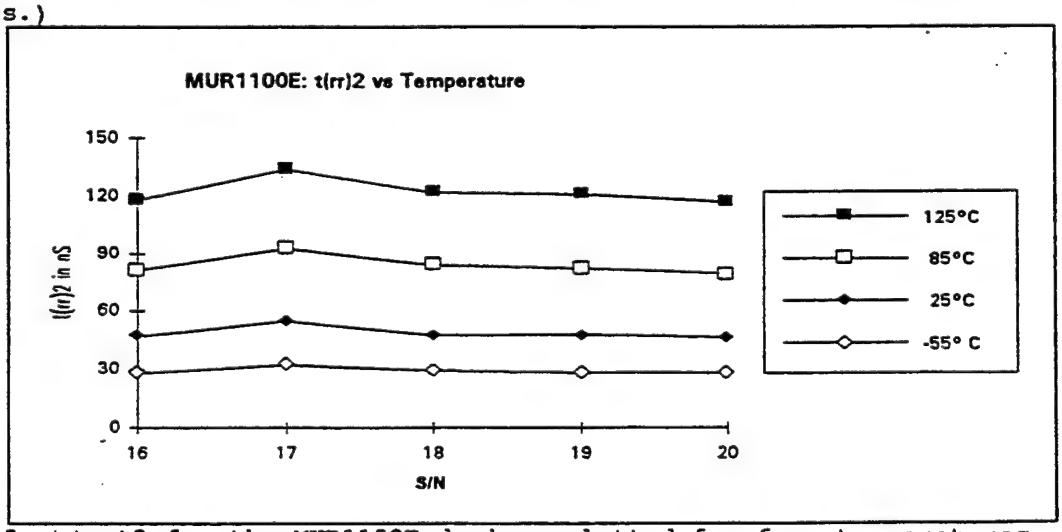

Figure T15. t(rr)2 for the MUR1100E devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

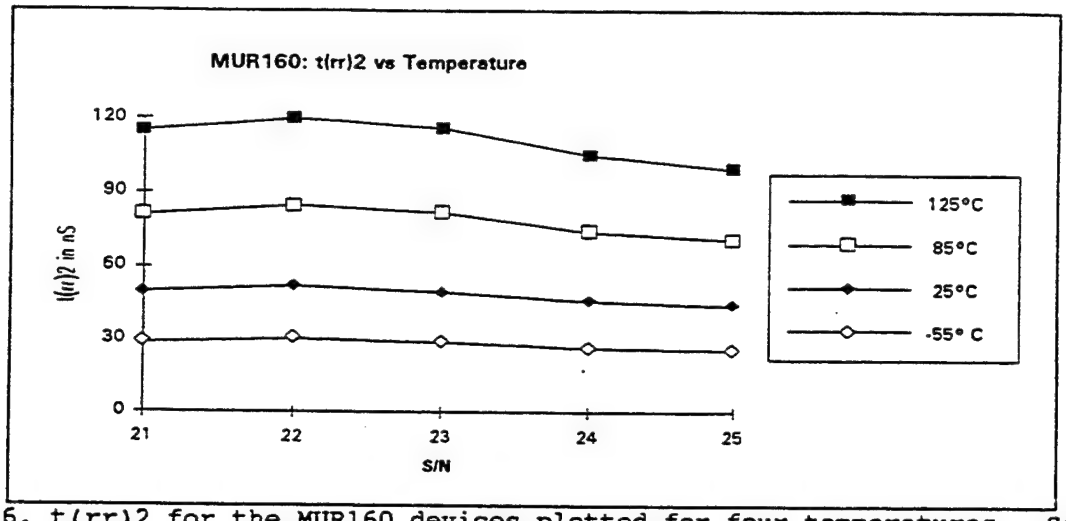

Figure T16. t(rr)2 for the MUR160 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

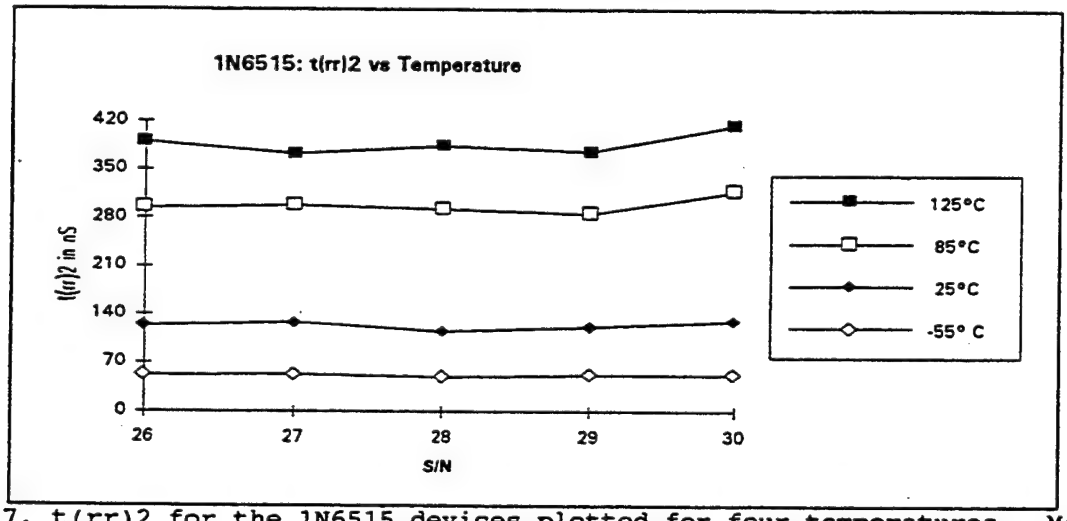

Figure T17. t(rr)2 for the 1N6515 devices plotted for four temperatures. Minor variation is seen from device to device. Variation with temperature is fairly consistent from device to device.

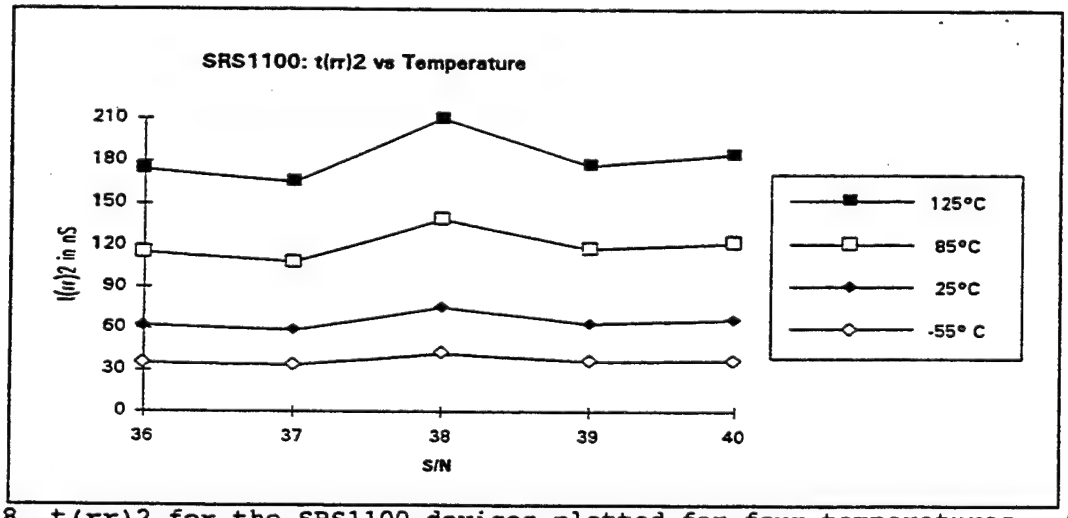

Figure T18. t(rr)2 for the SRS1100 devices plotted for four temperatures. Some variation is seen from device to device especially at 85 and 125°C. Variation with temperature is fairly consistent from device to device.

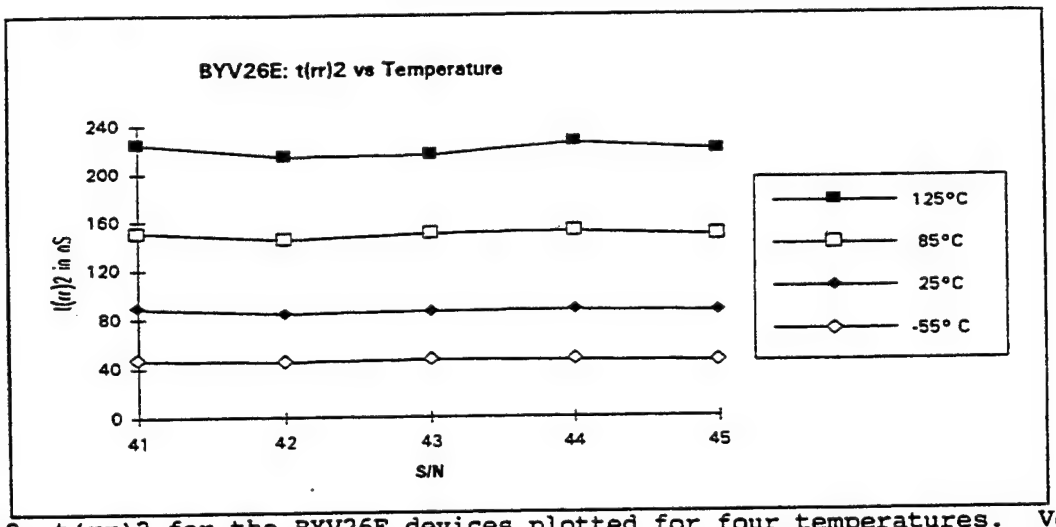

Figure T19. t(rr)2 for the BYV26E devices plotted for four temperatures. Very little variation is seen from device to device. Variation with temperature is very consistent from device to device.

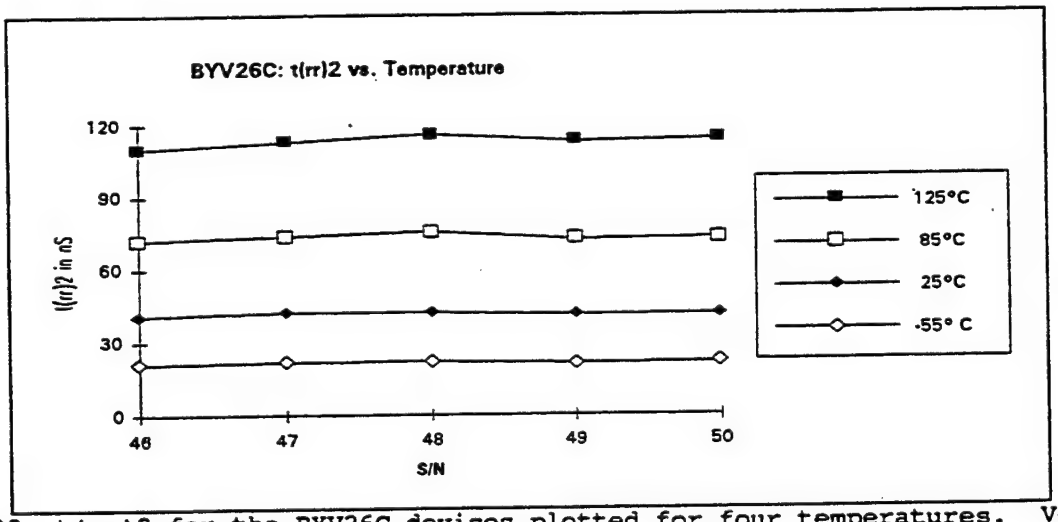

Figure T20. t(rr)2 for the BYV26C devices plotted for four temperatures. Very little variation is seen from device to device. Variation with temperature is very consistent from device to device.

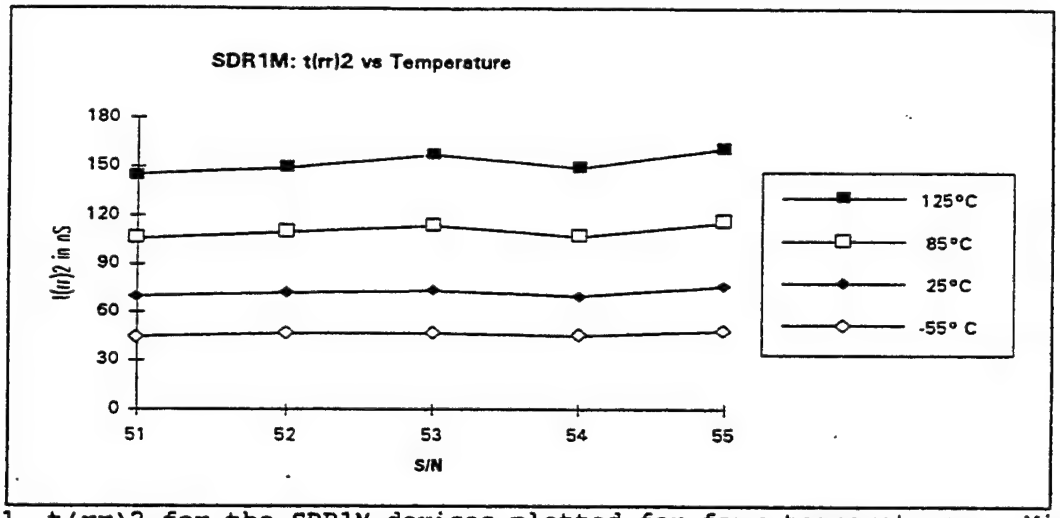

Figure T21. t(rr)2 for the SDR1M devices plotted for four temperatures. Minor variation is seen from device to device especially at 125°C. Variation with temperature is very consistent from device to device.

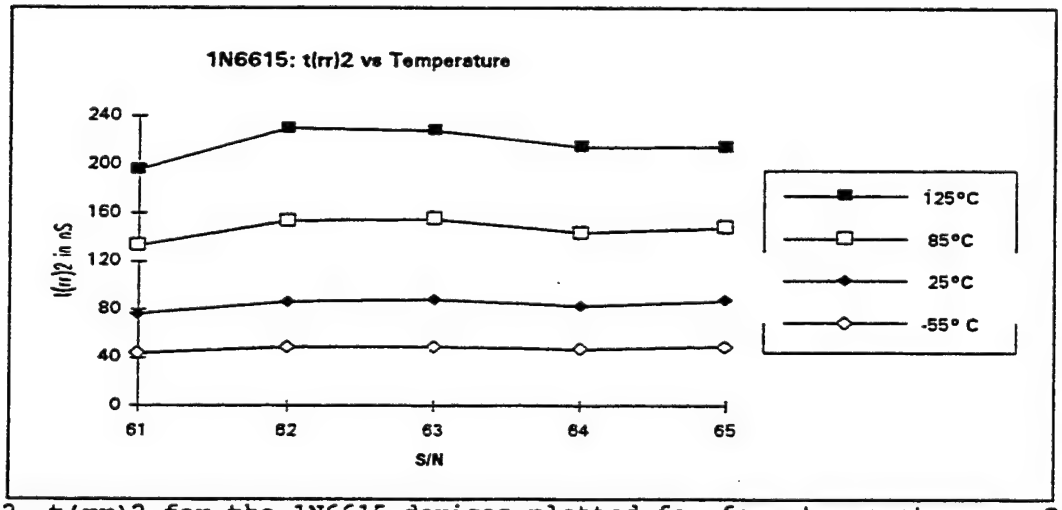

Figure T22. t(rr)2 for the 1N6615 devices plotted for four temperatures. Some variation is seen from device to device especially at 125°C. Variation with temperature is very consistent from device to device.

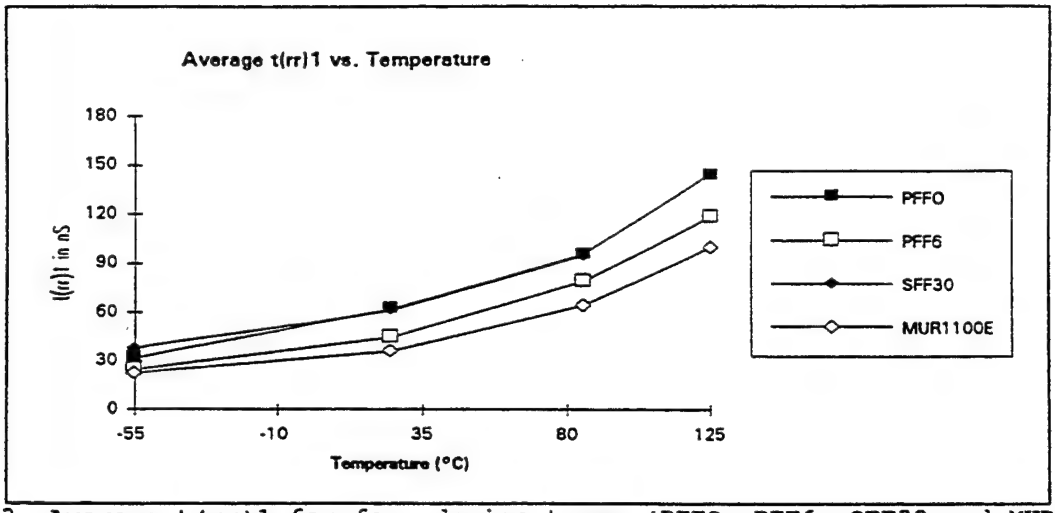

Figure T23. Average t(rr)1 for four device types (PFFO, PFF6, SFF30 and MUR1100) versus temperature. Variation with temperature is consistent from device type to device type.

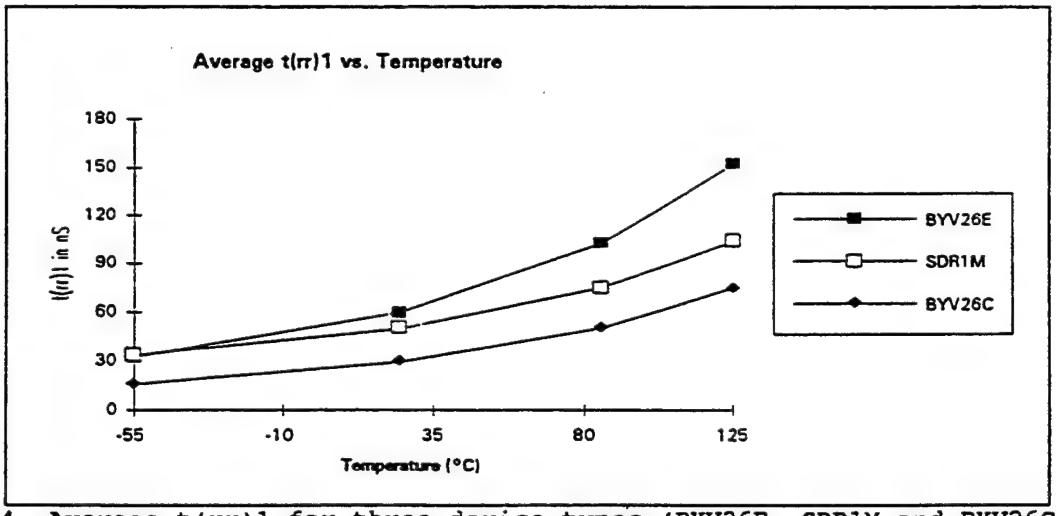

Figure T24. Average t(rr)1 for three device types (BYV26E, SDR1M and BYV26C) versus temperature. The BYV26E has a slightly higher temperature dependence than the other two device types which are similar.

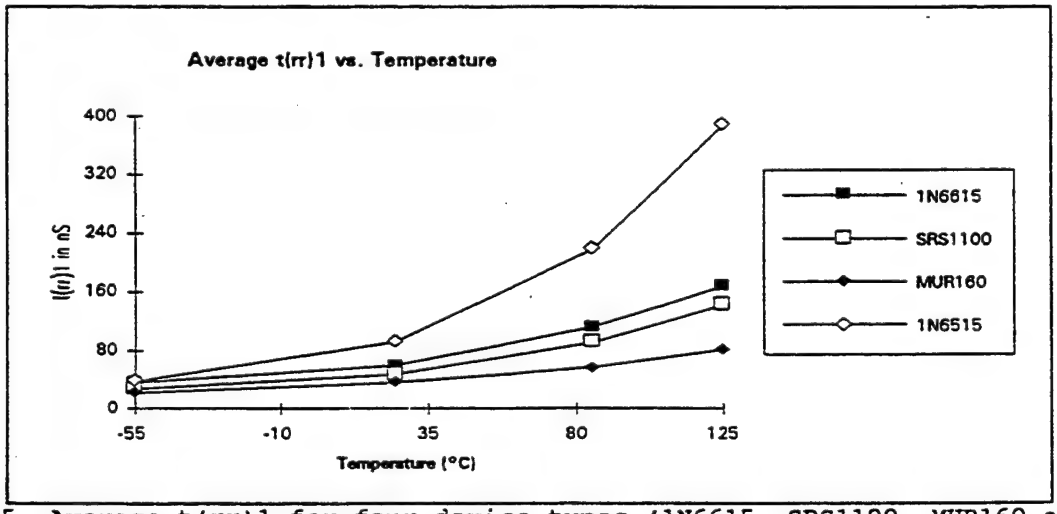

Figure T25. Average t(rr)1 for four device types (1N6615, SRS1100, MUR160 and 1N6515) versus temperature. The 1N6515 has a much higher temperature dependence than any of the other device types.

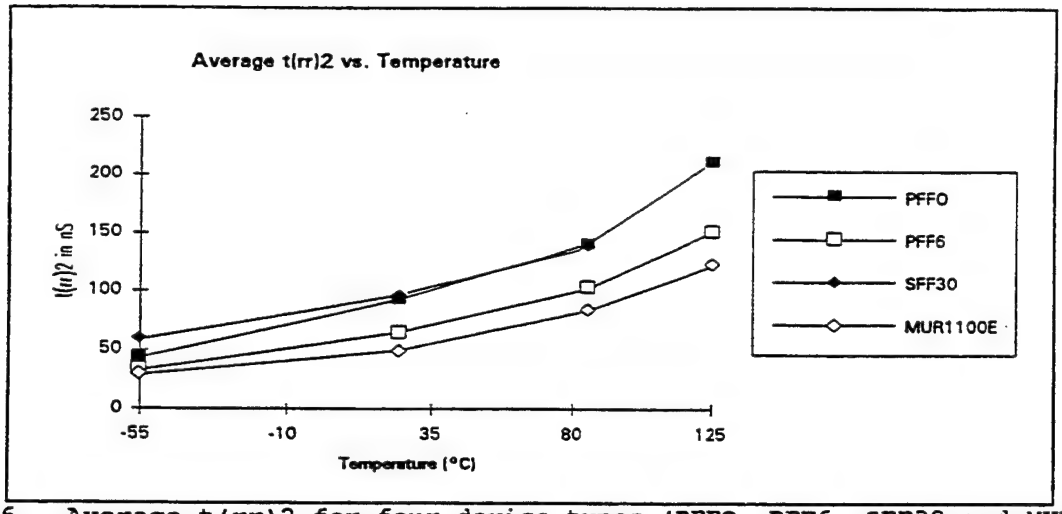

Figure T26. Average t(rr)2 for four device types (PFFO, PFF6, SFF30 and MUR1100) versus temperature. Variation with temperature is fairly consistent from device type to device type.

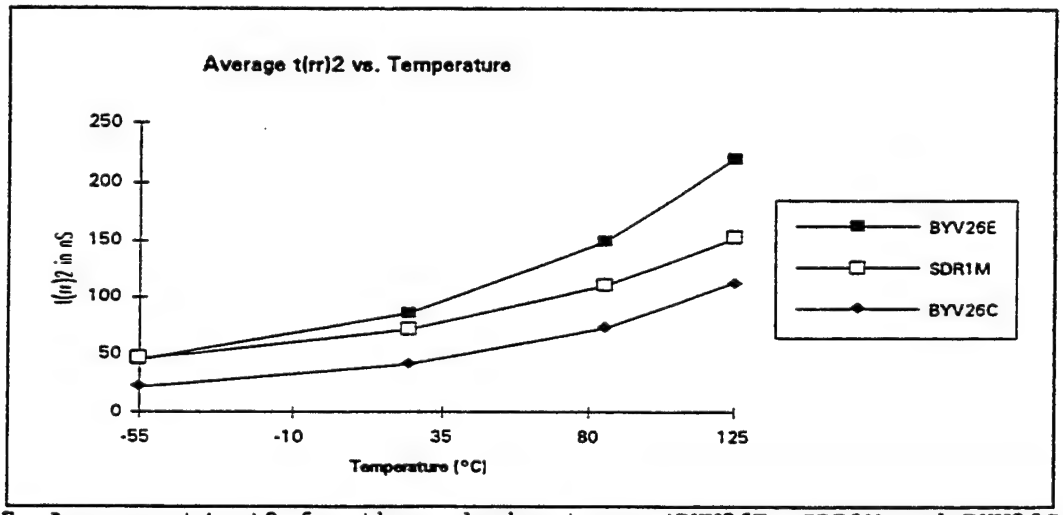

Figure T27. Average t(rr)2 for three device types (BYV26E, SDR1M and BYV26C) versus temperature. The BYV26E has a slightly higher temperature dependence than the other two device types which are similar.

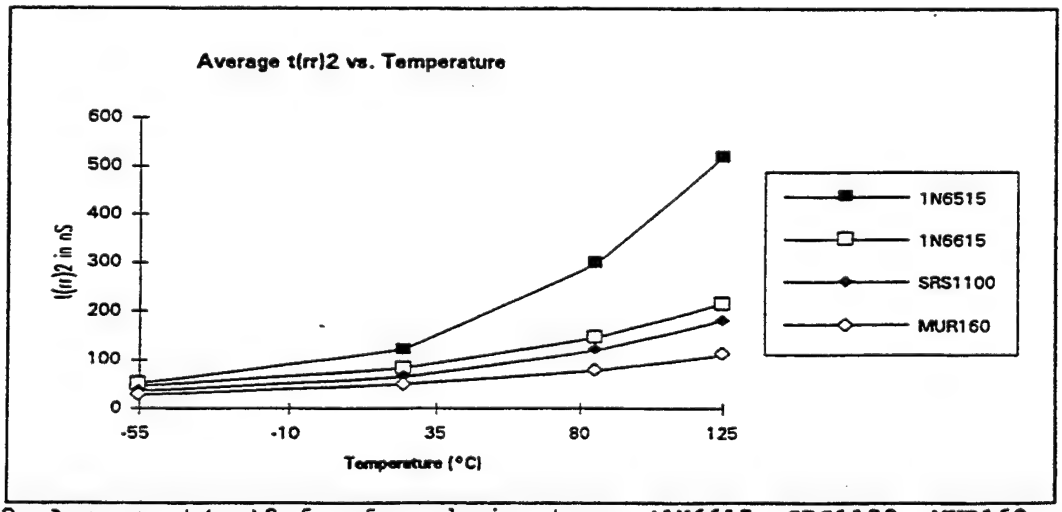

Figure T28. Average t(rr)2 for four device types (1N6615, SRS1100, MUR160 and 1N6515) versus temperature. Again, as in the case of the average t(rr)1 values, the 1N6515 has a much higher temperature dependence than any of the other device types.

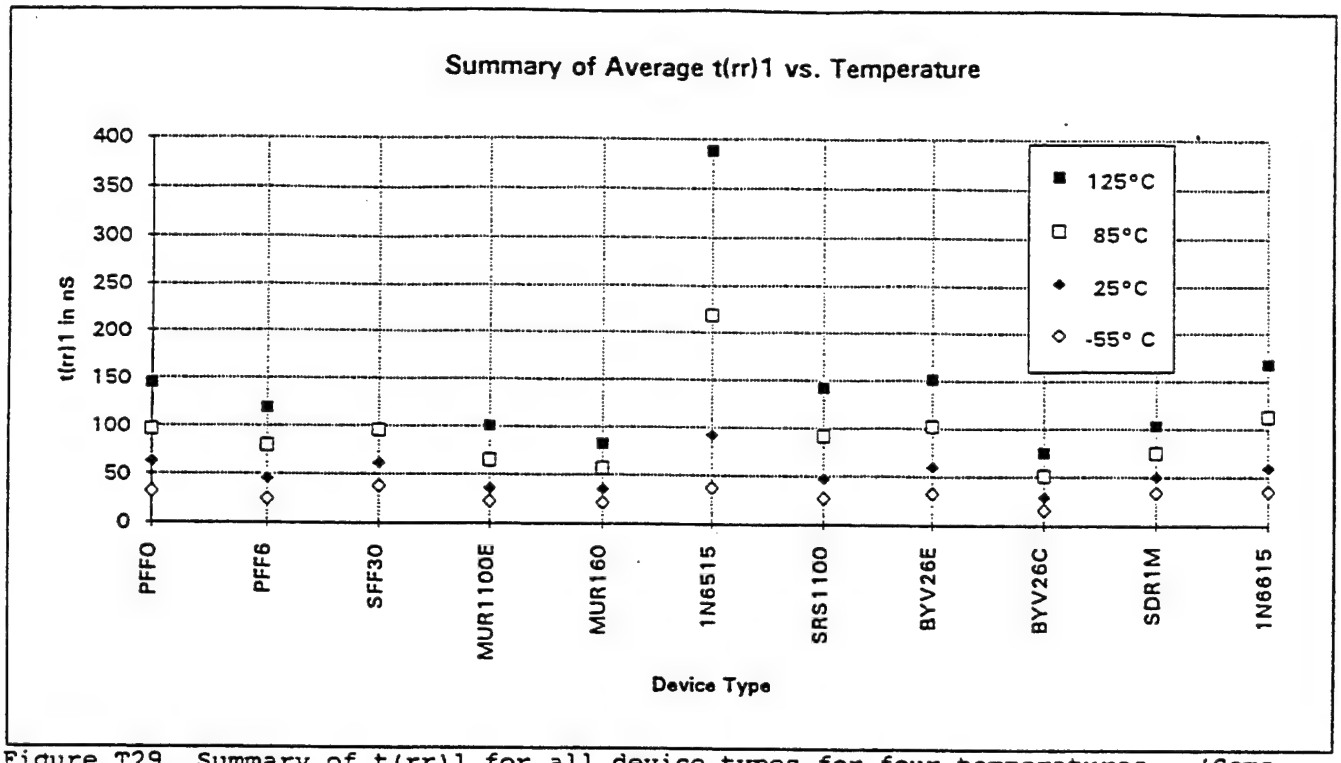

Figure T29. Summary of t(rr)1 for all device types for four temperatures. (Some device types did not have values for all four temperatures.)

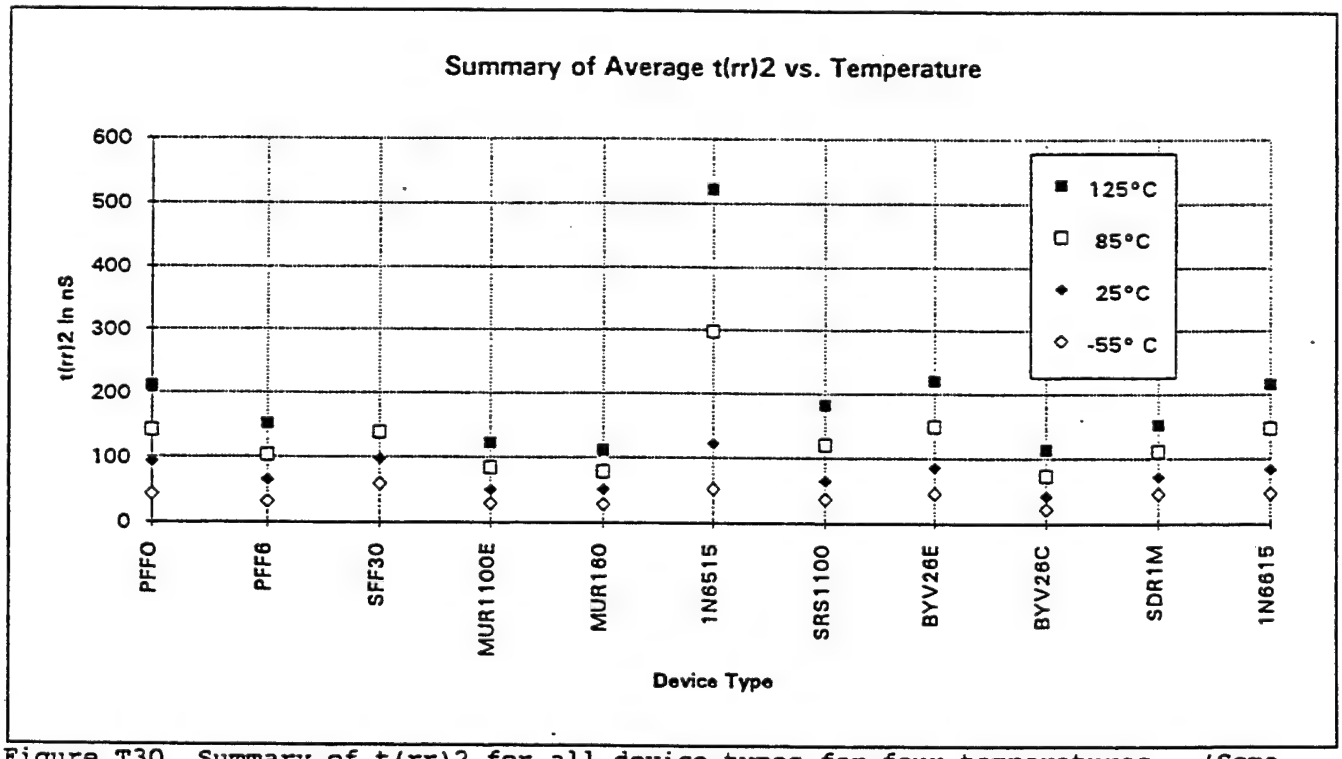

Figure T30. Summary of t(rr)2 for all device types for four temperatures. (Some device types did not have values for all four temperatures.)

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FOR HIGH VOLTAGE POWER SUPPLIES

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Manufacturing Guidelines

Introduction to the Silicone Material Section

2.0 Silicones

The silicone material program occupied a significant portion of this ManTech program. As a result a number of detailed methods and procedures were developed for inclusion in these manufacturing guidelines. Table 2.1 below introduces these essentially stand alone documents.

Figure 2.1, Detailed Silicone Material Processes

Para. No.	Title	Description
2.1	Designing a Significant Experiment for a normal distribution	How to design an experiment and analyze the data using the ANOVA method.
2.2	Mechanical Characterization of Silicone Rubber	Details for performing highly accurate optical measurements when testing an elastomer in tension. The Moire' method.
2.3	Sample Preparation of 4952N	How to Prepare flat samples of an elastomer for property testing.
2.4	Test Method for Tensile Properties of Eccosil 4952N	
2.5	Test Method for Tear Strength of Eccosil 4952N	
2.6	Detroit Testing Lab. Report	An example of a well documented test report from an outside laboratory.
2.7	Material Specification Guidelines	Detailed guidelines for preparing material specifications. A result of a Total Quality (TQ) team program.
2.8	Rev C for Eccosil 4952N material specification	Revised for this program to enhance the development of a Dock-To-Stock procurement procedure.

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

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2.1 Designing A Significant Experiment	2.1-3 to 2.1-13

Designing a Significant Experiment (Normal Distribution)

Sample Size:

To determine the sample size necessary to make a significant test, it is necessary to make some assumptions regarding distribution and expected variation. It is acceptable to assume that the data will be distributed normally for initial calculations. After the data is collected, there will be either confirmation of the distribution and variance or there will be enough data to determine the actual distribution and sample standard deviation.

The total population is defined by:

$$\int_{-\infty}^{+\infty} f(x) = \int_{-\infty}^{+\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} = 1 \ (100\%)$$

Since the limits of this integral are $+\infty$ and $-\infty$, the key paramenters, μ and σ are unknown and unknowable. Instead the estimators **X** and S are used. However the difference, $|\ \mathbf{X} - \mu\ |$ must be accounted for. The variable **a** expresses margin of error or distance from the true mean μ of **X**, the sample average.

The symbol **Z** is the number of standard deviations that will encompass a certain percentage of the population values. In other words a finite subset of the infinite is chosen so that some reasonable estimation can be obtained. This is referred to as the confidence level. For example, if z = 1.96:

$$\int_{-z}^{+z} f(x) = \int_{-z}^{+z} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} = .95$$

or contains 95% of the total population. Thus there would be a 95% confidence level attached to z = 1.96 for a two sided confidence.

For initial evaluation the sample size, n, can be calculated by the equation:

$$n = \left(\frac{z * \sigma_{est}}{a}\right)^2$$

where σ_{est} is an estimate of the population standard deviation.

Randomization of Experiment

Randomization is not randomly choosing samples for each treatment without thought. Instead randomization is the apportioning of samples so that anything that could cause variation not related directly to the treatments of the specimens is dispersed evenly among all of the treatments. For example, if the evaluation was city gas mileage among five different makes of automobile and four different drivers were going to test each car, there could still be a source of error if the cars were always driven at approximately the same time. One car could be driven during rush hour traffic and show a lower gas mileage than it would if driven when traffic was light. Since this variable of traffic really is really of no interest in this study, care would have to be taken that each car would be driven under equal conditions.

In material testing, sample preparation can be a major source of variation that is irrelevant to what is really of interest. To minimize this statistical "noise", great care must be taken to keep the sample preparation process as rigid as possible and to randomized the distribution of test specimens. Some of the steps necessary may be to have the same operator cast as many sheets as are needed to cut specimens for all testing at the same time in a multiple mold,and keep all process times as close as possible to some optimum value. For example, if the instructions are to cure material at 60 to 70°C for 18 to 20 hours, the sheets should be cured at 65° C for 19 hours.

Once the sheets are cast, specimens should be cut and assigned a designation that indicates the sheet from which they had been cut and the position within the sheet. The specimens are then to be apportioned to the test treatments in such a manner that each treatment recieves an equal number of specimens from each sheet and position. If each specimen is bounded by a specimen that undergoes a different treatment, cure and position will not become a variable between treatments. It is also recommended to keep some specimens as a retained sample in case of difficulties in testing or if the need for a referee test becomes apparent. See figure 1 for an example of randomization.

Figure 1 is a specific example of randomization applied by NG-ESD to the specimens to be tested for tensile strength and tensile modulus.

Four sheets were cast at one time in a multiple mold. Four was chosen after calculating the estimated significant sample size for testing (20) and mutiplying that by the number of prospective test sites (3) + one set to be kept as a retain in case of any complications.

The sheets were assigned the designation of A,B,C,and D where A and D were the outside of B and D. Each specimen was then cut and assigned a number indicating it's position within the sheet. The specimens were then apportioned so that all test sites got approximately equal numbers of specimens from each sheet and position.

NORTHROP	BROUTMAN	E & C	RETAINED
A1	A2	A3	A4
A5	A6	A7	A8
A9	A10	A11	A12
A13	A14	A15	A16
A17	A18	A19	A20
A21	A22		B1
B2	B3	B4	B5
B6	B7	B8	B9
B10	B11	B12	B13
B14	B15	B16	B17
B18	B19	B20	B21
B22		C1	C2
C3	C4	C5	C6
C7	C8	C9	C10
C11	C12	C13	C14
C15	C16	C17	C18
C19	C20	C21	C22
	D1	D2	D3
D4	D5	D6	D7
D8	D9	D10	D11
D12	D13	D14	D15
D16	D17	D18	D19
D20	D21	D22	

In this way any influence on the test results within a single batch of material by sample preparation, curing and position was minimized.

Analyzing the Data:

The first action that must be taken on test data is to eliminate outlying values. Any value that is suspect due to an attributable cause must be eliminated even if the value looks like it fits into the rest of the data set. Otherwise the set is biased and no longer random. An example of attributable cause is an identifyable defect in the test specimen or momentary malfunction of test equipment. Once the attributable have been eliminated, the rest of the set may be evaluated for outliers by one of the standard methods described in ASTM E 178. If the outlier check may have several iterations, the recommended method is the check for skewness (bias to on side) and kurtosis (excessive spread in the data.)

After the data has been edited, it is necessary to determine whether or not there is a real difference in the effects of the treatments. Rather than make subjective judgements about the data, it is desirable to be able to determine the source of the variation and determine how much of the total variation is due to the actual treatments of the test sets and how much is due to error or chance. Otherwise there would be a tendency to see exactly what would confirm preexisting opinions rather than be able to make an objective appraisal. A relatively simple method for evaluating the data is **ANOVA** (Analysis of Variance).

ANOVA uses the sum of squares to determine the amount of error "between" data sets and "within" the data sets. Every test value is recorded as $x_{i,j}$ where i indicates the treatment and j is the replication. The equation for this is:

$$\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{i,j}-\overline{x})^2 = \sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{i,j}-\overline{x}_i)^2 + \sum_{i=1}^{k} n_i(\overline{x}_i-\overline{x})^2$$

Total Sum of Squares = Error Sum of Squares + Treatment Sum of Squares

where $\overline{x}_i$ = *the average of each treatment*
$\overline{x}$ *(or* $\mathbf{X}$*)* = *the grand average*
n_i = *the number of values within each treatment*
and k = *the number of treatments*

There are simplifications of this equation but the use of these is predicated on having an equal number of specimens for each treatment. In the real world, and especially when dealing with materials, some specimens may have to be eliminated leaving unequal numbers in the sets. If this is not considered, data analysis will become invalid.

In the example below, the question is whether on not dielectric constant varies with material batch. All specimens were tested at 100 kHz at a commercial laboratory in accordance to ASTM D-150. The material was Emerson & Cuming 4952 N, a filled condensation cured silicone rubber. Samples were cast from three different batches of material and six specimens were tested from each batch.

$x_{i,j}$	Batch 33	Batch 47	Batch 30
1	2.81	2.82	2.80
2	2.82	2.82	2.81
3	2.83	2.84	2.81
4	2.83	2.85	2.82
5	2.84	2.85	2.83
6	2.85	2.86	2.86

$\mathbf{n}_i$	6	6	6
average or $\mathbf{X}_i$	2.83	2.84	2.82

The overall or grand average, $\mathbf{X}$, is calculated by $\sum x_{i,j} \div \sum n_i$

The squares of the individual values are now calculated

$x_{i,j}^2$	$x_{1,j}^2$	$x_{2,j}^2$	$x_{3,j}^2$
1	7.8961	7.9524	7.84
2	7.9524	7.9524	7.8961
3	8.0089	8.0656	7.8961
4	8.0089	8.1225	7.9524
5	8.0656	8.1225	8.0089
6	8,1225	8.1796	8.1796

The Total Sum of Squares (TSS) is calculated by subtracting the grand or overall average **X** from each individual $x_{i,j}$ and squaring the result. These values are then added together to obtain TSS.

$(x_{i,j} - \mathbf{X})^2$	$(x_{1,j} - \mathbf{X})^2$	$(x_{2,j} - \mathbf{X})^2$	$(x_{3,j} - \mathbf{X})^2$
1	.00042	.00011	.00093
2	.00011	.00011	.00042
3	.00000	.00009	.00042
4	.00000	.00038	.00011
5	.00009	.00038	.00000
6	.00037	.00087	.00086

In this case TSS = .00569

The Error Sum of Squares (ESS) is calculated by subtracting the treatment averages $\mathbf{X}_i$ from the individual values of $x_{i,j}$. This remainder is squared and these values are added together to calculate ESS.

$(x_{i,j} - \mathbf{X}_i)^2$	$(x_{1,j} - \mathbf{X}_1)^2$	$(x_{2,j} - \mathbf{X}_2)^2$	$(x_{3,j} - \mathbf{X}_3)^2$
1	.00040	.00040	.00047
2	.00010	.00040	.00014
3	0	0	.00014
4	0	.00010	.00000
5	.00010	.00010	.00069
6	.00040	.00040	.00147

For these values, ESS = .00468

The Treatment Sum of Squares may either be calculated from the equation or simply determined by TSS - ESS = TrSS or .00101.

It is now possible to calculate the Mean Squares for the error and the treatments. This is accomplished by dividing the Sum of Squares for each by the correct Degrees of Freedom. The number of Degrees of Freedom for treatments (ν_1) is defined as one less than the number of treatments. Thus, since there are Three batches of material (our treatments) there are 2 Degrees of Freedom for treatment. The Mean Square then becomes .00051. The number of Degrees of Freedom for error (ν_2) is defined as the total number of samples ($\lceil n_i$) minus the number of treatments. From this it is calculated that the number of Degrees of Freedom for error is:

18 total specimens - 3 treatments = 15 DF for error.
The Mean Square for error is .00031.

Statistical Significance of the treatments is determined by:

$$F = \frac{Mean\ Square_{treatment}}{Mean\ Square_{error}}$$

In this case, F = 1.619. To decide the significance of this, it is necessary to compare the calculated value to a predetrmined standard. These standard F values have been tabulated for several levels of confidence and can be found in most statisics books. Figure 2 illustrates the F table used in these example. In this case where $\nu_1 = 2$, $\nu_2 = 5$, and the preferred confidence level is 95% ($\alpha = .05$), $F_{table} = 5.79$. Since $F_{calc} < F_{table}$, it must be concluded that there is no significant difference in dielectric constant between material batches at 100 kHz.

The second example, Volume Resistivity per ASTM D-257, illustrates both an uneven sample size for each treatment and a case where $F_{calc} > F_{table}$. The material is, again, Emerson & Cuming 4952N. In this case, because of the unequal sample size, simpifying the equations would disallow the comparison.

Volume Rstv	Batch 1	Batch 2	Batch 3
1	1.58E+13	6.13E+13	6.01E+13
2	5.64E+13	6.95E+13	6.74E+13
3	2.85E+13	2.79E+13	8.22E+13
4	4.74E+13	2.22E+13	5.82E+13
5	4.75E+13	4.1E+13	7.35E+13
6	4.74E+13	5.64E+13	9.19E+13
7		8.85E+13	
8		5.37E+13	

$\mathbf{X}_i$	4.050E+13	4.261E+13	7.222E+13
n_i	6	8	6

$(x_{i,j} - \mathbf{X})^2$	$(x_{1,j} - \mathbf{X})^2$	$(x_{2,j} - \mathbf{X})^2$	$(x_{3,j} - \mathbf{X})^2$
1	1.229E+27	1.090E+26	8.542E+25
2	3.072E+25	3.475E+26	2.737E+26
3	4.999E+26	5.270E+26	9.824E+26
4	1.195E+25	8.213E+26	5.391E+25
5	1.127E+25	9.717E+25	5.127E+26
6	1.195E+25	3.072E+25	1.684E+27
7		1.765E+27	
8		8.080E+24	

Total Sum of Squares = 9.093E+27

$(x_{i,j} - \mathbf{X}_i)^2$	$(x_{1,j} - \mathbf{X}_1)^2$	$(x_{2,j} - \mathbf{X}_2)^2$	$(x_{3,j} - \mathbf{X}_3)^2$
1	6.101E+26	3.495E+26	1.468E+26
2	2.528E+26	7.233E+26	2.320E+25
3	1.440E+26	2.163E+26	9.967E+25
4	4.761E+25	4.164E+26	1.965E+26
5	4.900E+25	2.580E+24	1.647E+24
6	4.761E+25	1.903E+26	3.874E+26
7		1.139E+27	
8		1.231E+26	

Error Sum of Squares = 5.167E+27

Treatment Sum of Squares = 3.926E+27

$DF_{treatment}$ = 2
DF_{error} = 17
$MS_{treatment}$ = 1.963E+27
MS_{error} = 3.040E+26

F = 6.458

At 95% confidence F_{table} = 3.59
Since this is less than the calculated F there is a significant difference in Volume Resistivity between batches of material.

Figure 1

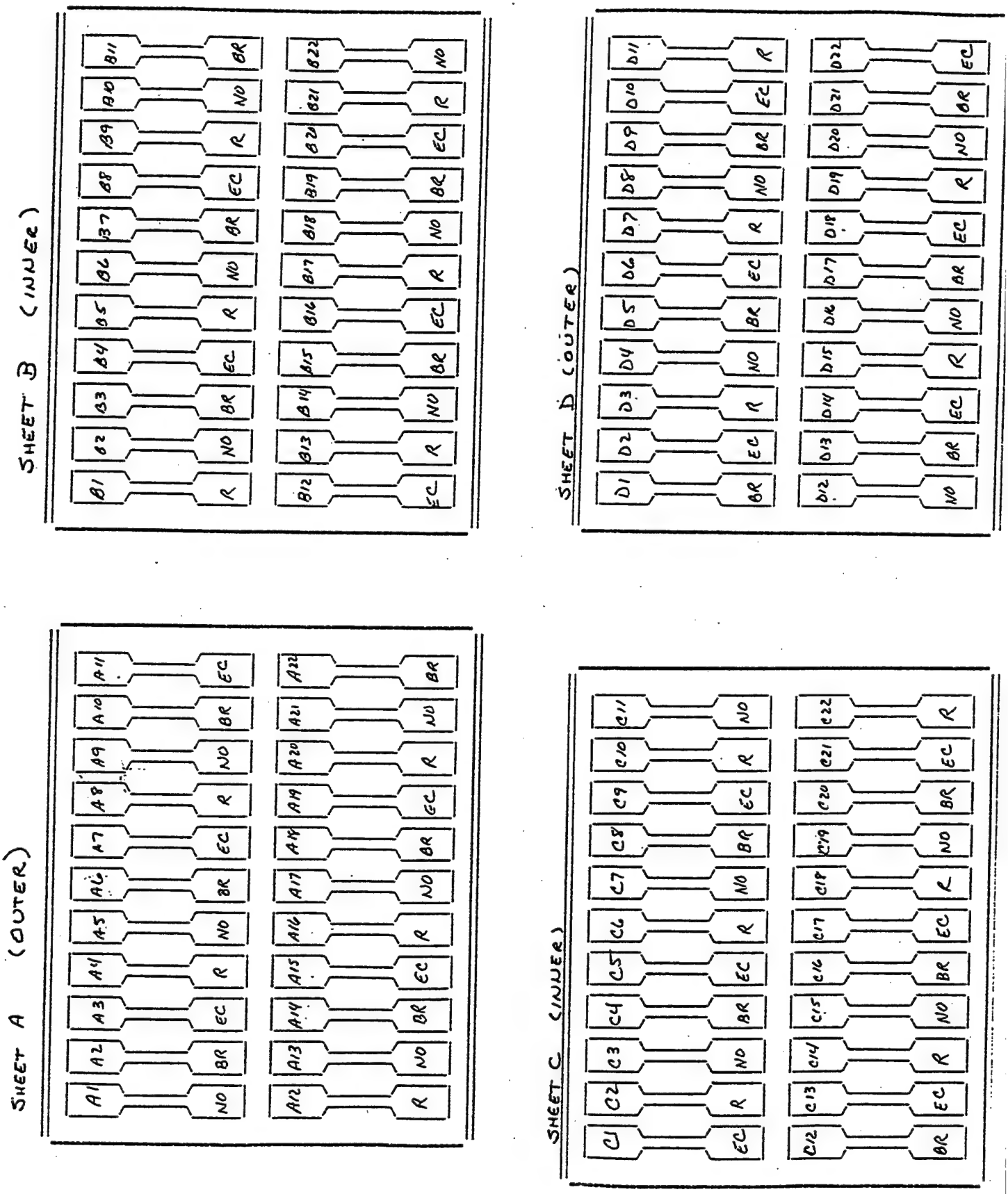
SHEET A (OUTER)
A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11
NO BR EC R NO BR EC R NO BR EC
A12 A13 A14 A15 A16 A17 A18 A19 A20 A21 A22
R NO BR EC R NO BR EC R NO BR
SHEET B (INNER)
B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11
R NO BR EC R NO BR EC R NO BR
B12 B13 B14 B15 B16 B17 B18 B19 B20 B21 B22
EC R NO BR EC R NO BR EC R NO
SHEET C (INNER)
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11
EC R NO BR EC R NO BR EC R NO
C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22
BR EC R NO BR EC R NO BR EC R
SHEET D (OUTER)
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11
BR EC R NO BR EC R NO BR EC R
D12 D13 D14 D15 D16 D17 D18 D19 D20 D21 D22
NO BR EC R NO BR EC R NO BR EC

Figure 2

95% CONFIDENCE

Degrees of freedom for the denominator (ν_2)	Degrees of freedom for the numerator (ν_1)																	
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
1	161	200	216	225	230	234	237	239	241	242	243	244	245	245	246	246	247	247
2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.76	8.74	8.73	8.71	8.70	8.69	8.68	8.67
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.94	5.91	5.82	5.87	5.86	5.84	5.83	5.82
5	6.61	5.79*	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.70	4.08	4.66	4.64	4.62	4.60	4.59	4.58
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.03	4.00	3.98	3.96	3.94	3.92	3.91	3.90
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.60	3.57	3.55	3.53	3.51	3.49	3.48	3.47
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.31	3.28	3.26	3.24	3.22	3.20	3.19	3.17
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.10	3.07	3.05	3.03	3.01	2.99	2.97	2.96
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.94	2.91	2.89	2.86	2.85	2.83	2.81	2.80
11	4.84	2.98	3.50	3.36	3.20	3.01	2.95	2.90	2.85	2.82	2.82	2.79	2.76	2.74	2.72	2.70	2.69	2.67
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.72	2.69	2.66	2.64	2.62	2.60	2.58	2.57
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.63	2.60	2.58	2.55	2.53	2.51	2.50	2.48
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.57	2.53	2.51	2.48	2.46	2.44	2.43	2.41
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.51	2.48	2.45	2.42	2.40	2.38	2.37	2.35
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.46	2.42	2.40	2.37	2.35	2.33	2.32	2.30
17	4.45	3.59**	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.41	2.38	2.36	2.33	2.31	2.29	2.27	2.26
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.37	2.34	2.31	2.29	2.27	2.25	2.23	2.22
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.34	2.31	2.28	2.26	2.23	2.21	2.20	2.18
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.31	2.28	2.25	2.22	2.20	2.18	2.17	2.15
21	4.32	3.47	3.07	2.82	2.68	2.57	2.49	2.42	2.37	2.32	2.28	2.25	2.22	2.20	2.18	2.16	2.14	2.12
22	4.30	3.44	3.05	2.84	2.66	2.55	2.46	2.40	2.34	2.30	2.26	2.23	2.20	2.17	2.15	2.13	2.11	2.10
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.23	2.20	2.18	2.15	2.13	2.11	2.09	2.07
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.21	2.18	2.15	2.13	2.11	2.09	2.07	2.05
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.20	2.16	2.14	2.11	2.09	2.07	2.05	2.04
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.18	2.15	2.12	2.09	2.07	2.05	2.03	2.02
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.17	2.13	2.10	2.08	2.06	2.04	2.02	2.00
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.15	2.12	2.09	2.06	2.04	2.02	2.00	1.99
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.14	2.10	2.08	2.05	2.03	2.01	1.99	1.97
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.13	2.09	2.06	2.04	2.01	1.99	1.98	1.96
32	4.15	3.29	2.90	2.67	2.51	2.40	2.31	2.24	2.19	2.14	2.10	2.07	2.04	2.01	1.99	1.97	1.95	1.94
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29	2.23	2.17	2.12	2.08	2.05	2.02	1.99	1.97	1.95	1.93	1.92
36	4.11	3.26	2.87	2.63	2.48	2.36	2.28	2.21	2.15	2.11	2.07	2.03	2.00	1.98	1.95	1.93	1.92	1.90
38	4.10	3.24	2.85	2.62	2.46	2.35	2.26	2.19	2.14	2.09	2.05	2.02	1.99	1.96	1.94	1.92	1.90	1.88
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.04	2.00	1.97	1.95	1.92	1.90	1.89	1.87

* EXAMPLE 1

** EXAMPLE 2

DESIGN AND MANUFACTURING GUIDELINES

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Mechanical characterization of Silicone Rubber

1.0 SCOPE

This document describes an experimental method for making precise measurements of the Elastic Modulus (E) and Poisson's Ratio (μ) of elastomeric materials in the low strain range (less than 10 percent) as a function of temperature. The work was done by Dr. Isaac M. Daniel of the McCormick School of Engineering and Applied Science at Northwestern University in Evanston, Illinois and is contained in a report prepared for the Northrop Corporation in December, 1991. The procedure involves a process developed by Dr. Daniel using the technique of Moiré interference patterns.

2.0 Experimental Procedure

The work described herein was conducted on two commercially available silicone potting materials, Eccosil 4952N (Emerson and Cuming) and RTV-615 (GE Silicones). The Eccosil 4852N is a heavily filled (aluminum oxide) red pigmented material. RTV-615 is an unfilled and transparent material. The material was provided by Northrop Corporation in the form of cast and cured 10 X 12 X 0.125 inch sheets. Test samples were prepared from these sheets in the form of coupons 1 inch wide, 9 inches long and 0.125 inches thick. These specimens were prepared with Moiré grids as described below for the measurement of axial and transverse strains under loading. It was decided to use arrays of 300 lines per inch in the Moiré tests. A glass master with this line density was obtained. A transfer technique using a commercially available strippable film was used to transfer arrays of 300 lines/inch on the specimen surface. The first task was to copy the array from the glass master onto the strippable film. The film used was I.N.T. (Image 'N Transfer) film manufactured by 3M Company. This film has a presensitized opaque adhesive coating on a polyester base. The adhesive is protected by a removable clear liner and a brown colored layer. The set up for copying the array on the I.N.T. film is illustrated in Figure 1.

The glass master with the emulsion side down is placed over the I.N.T. film which is placed with the brown side down over a sheet of black paper and a glass plate for support. The film is exposed through the glass master by means of a 100 W ultraviolet light source placed at a distance of 20 inches. The procedure used follows:

1. Expose film for 3 min. 20 sec.
2. Peel off clear gelatin liner on the brown side of the film.

3. Rub off the brown colored protective layer with a water moistened cotton wipe.
4. Develop film for 30 sec. in a tank with I.N.T. developer.
5. Wash off unexposed emulsion and rinse.
6. Dry film.

7. Check film for quality by overlaying it over the glass master and observing the resulting Moiré fringes.

The next task was to transfer the array from the film onto the specimen surface. This task consists of the following steps:

1. Apply primer (SS-4044, GE Co.) to both the specimen surface and film. Allow primer to dry for one hour.
2. Mix RTV-11 (GE Silicones) with catalyst and apply to specimen surface.
3. Attach I.N.T. film to RTV-coated surface and apply pressure with a glass plate (5-10 psi)
4. Cure RTV with film for 24 hr. at room temperature.
5. Peel off clear (polyester) backing to leave only the array lines of the film on the specimen.

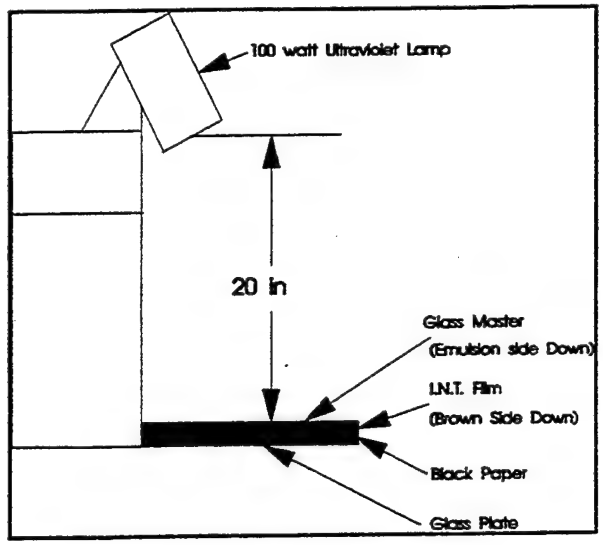


Figure 1, Grid Preparation

Two arrays were printed on each half of the specimen, one with the lines horizontal for determination of axial strains and the other with the lines vertical for determination of transverse strains.

The specimens with the attached arrays of lines were gripped in a specially designed fixture and loaded through a 300 lb. load cell in a servohydraulic testing machine. Film copies of the master array were placed in contact with the specimen arrays by means of a film of oil. Thus, upon loading, the deformed specimen arrays interfere with the undeformed master to produce Moiré fringes. For a uniform strain field the fringes are parallel and equidistant. The (average) strain normal to the array lines over a gage length l is obtained as

$$\epsilon = np/l$$

where n = number of Moiré fringes over the gage length

l = gage length
p = pitch (or line spacing) of moiré master

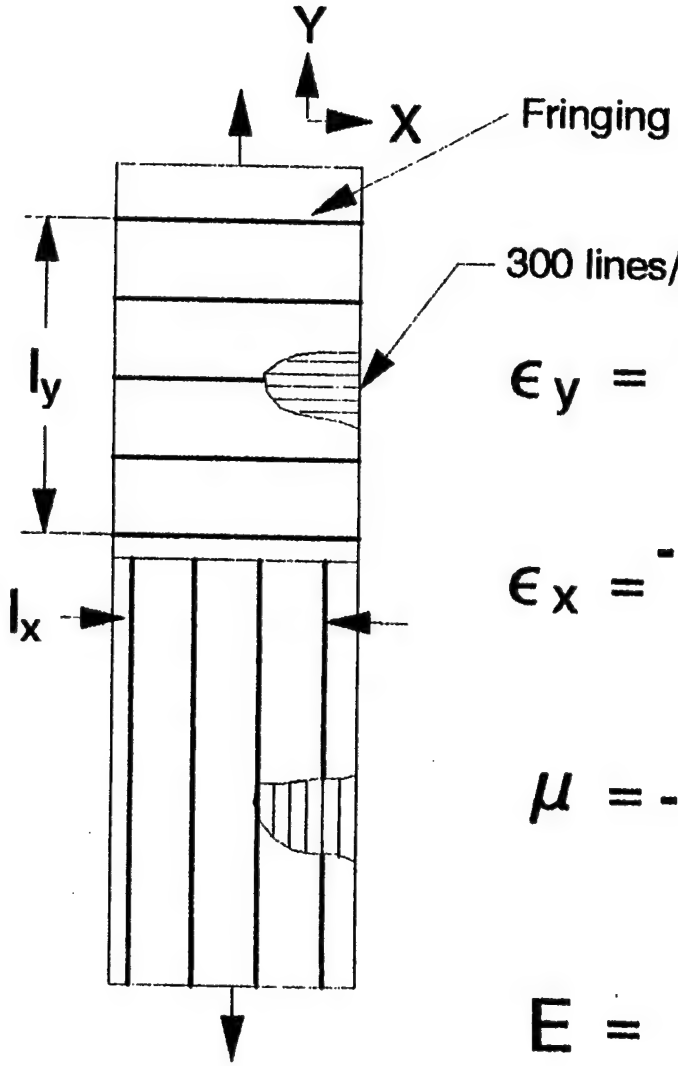
Figure 2 illustrates this process pictorially.

The specimens were loaded continuously at a crosshead rate of 0.4 inches/minute while intermittently taking photographs of the fringe patterns. Tests were conducted inside a thermal chamber over a temperature range of -43°C (-45°F) to 93°C (200°F). Photographs were taken through the window of the chamber. Difficulties were encountered in photographing the patterns at sub zero temperatures due to extensive fogging inside the chamber.

2.1 Results

A typical Moiré fringe patterns at various applied stresses at room temperature is shown in Figure 3. Strains obtained from these patterns are plotted as a function of applied stress as shown in Figure 4. The modulus is obtained from the slope of the stress versus longitudinal strain curve and Poisson's ratio is obtained from the ratio of the slopes of the two curves, i.e., stress versus transverse strain and stress versus longitudinal strain. Poisson's ratio is also obtained from the slope of the transverse versus axial strain curve as shown in Figure 5.

The stress-strain curves appear linear at least up to an axial strain of 8 percent, indicating that both modulus and Poisson's ratio are constant, at room temperature, up to this strain level. Several tests were conducted at room temperature and results were analyzed during loading unloading and reloading cycles. No significant differences were detected due to reloading, indicating that no measurable damage was induced in the material up to this uniaxial strain level. Small variations in the modulus and Poisson's ratio values were attributed to experimental variability from specimen to specimen and from test to test, due to the many factors involved. An error analysis on the Poisson's ratio showed that the determinations were accurate to within +/- 0.005.



$$\epsilon_y = \frac{4(1/300)}{l_y} \quad \text{(4 fringes)}$$

$$\epsilon_x = \frac{-3(1/300)}{l_x} \quad \text{(3 fringes)}$$

$$\mu = -\frac{\epsilon_x}{\epsilon_y} \quad \text{(Poisson's Ratio)}$$

$$E = \frac{\sigma}{\epsilon_y} \quad \text{(Young's Modulus)}$$

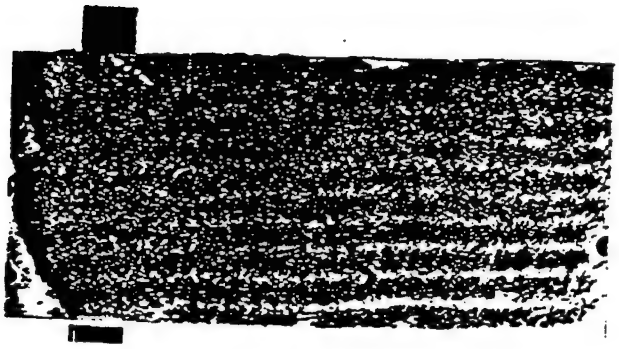
Figure 2 **The MOIRE' Method**

Figure 3

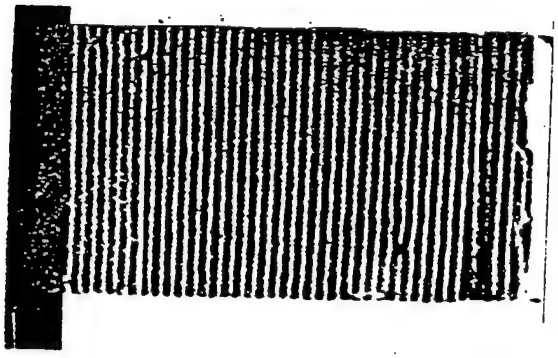
MOIRÉ TESTING ON SILICONE RUBBER

Load cell 25 lbs calibration number 0.904 lb/mv
grating 300 lines/in. gage length 1.3129 in.
thickness 0.140 in. width 1.020 in.
Specimen 2 - 2

Transverse (54.7851 psi)



Longitudinal (54.6129 psi)



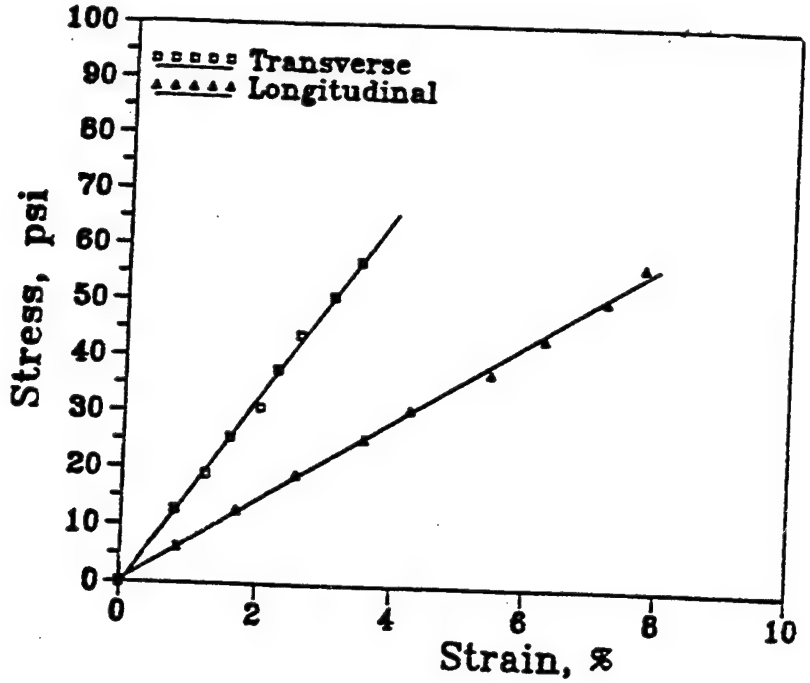


Figure 4 Stress-Strain of 4952N

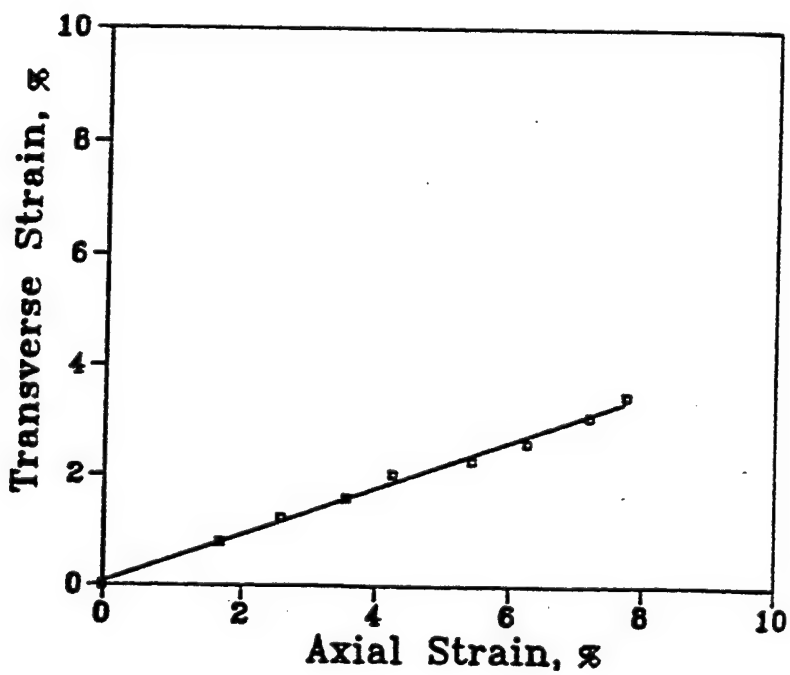


Figure 5 Strain-Strain of 4952N

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SAMPLE PREPARATION OF 4952N

EQUIPMENT:

1. Molding plates, 10" x 12" x 0.125", Teflon coated tool steel. See drawing
2. Washers, 0.125" thick
3. Vacuum Chamber, capable of drawing to at least 10 millimeters of mercury (TORR)
4. Mixer, motor or air driven
5. Beakers, clean and dry, Polyethylene or other nonabsorbant, inert material
6. Balance, capable of measuring to 0.1 gram or better.
7. Kapton or equivalently adhesive and inert tape.

CHEMICALS:

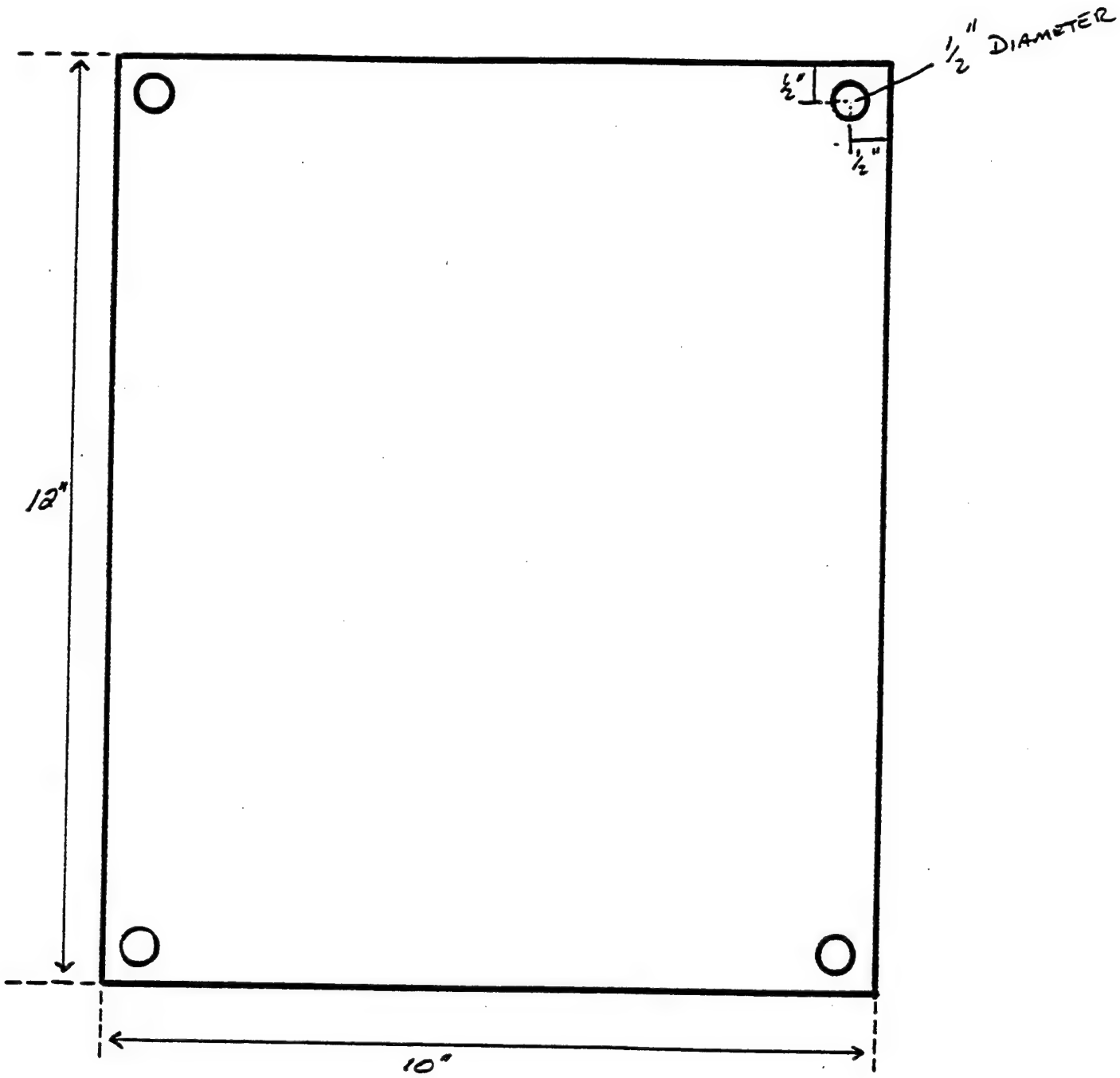
Emerson & Cuming Eccosil 4952N
Emerson & Cuming Catalyst 50

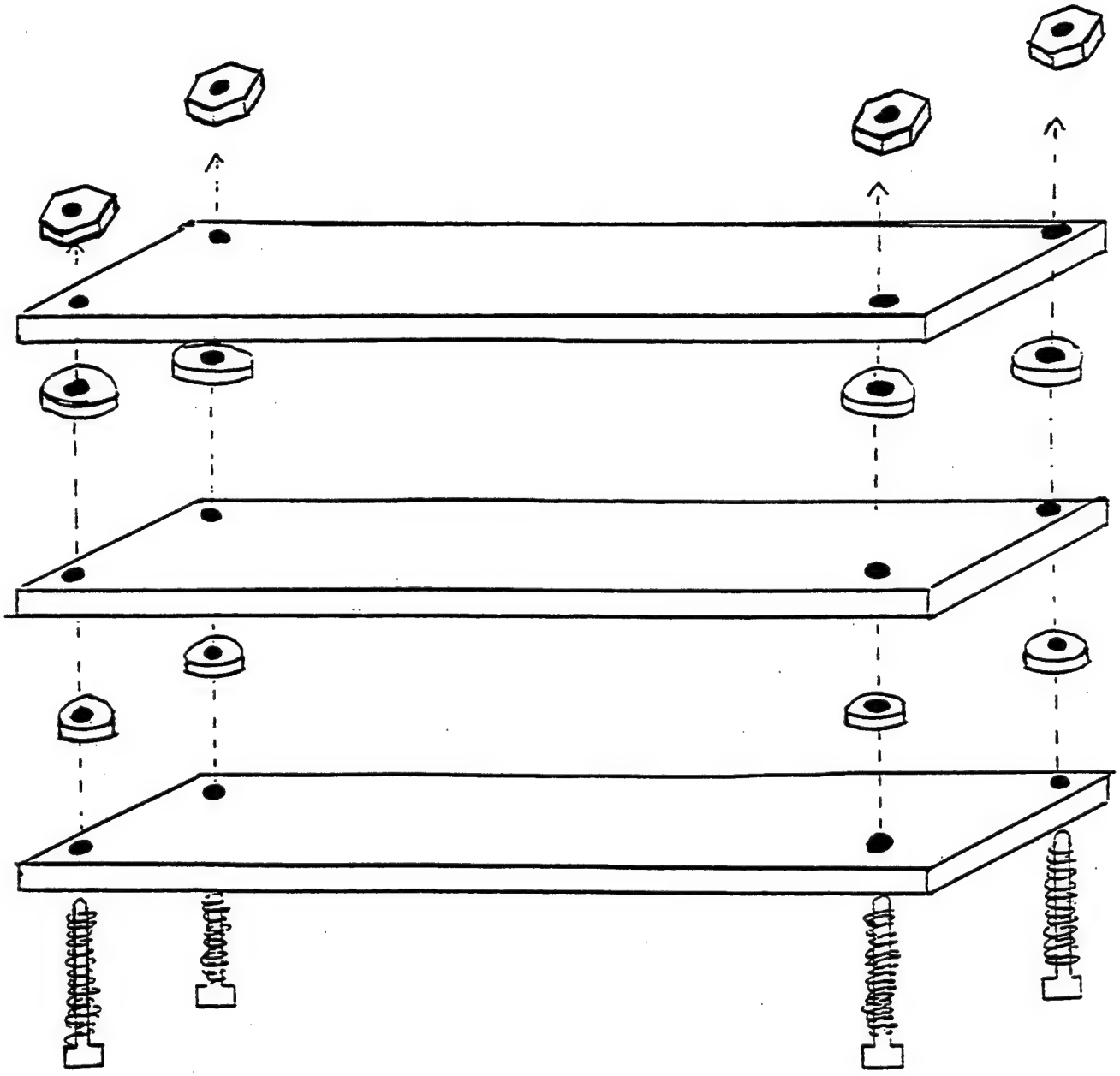
PROCEDURE:

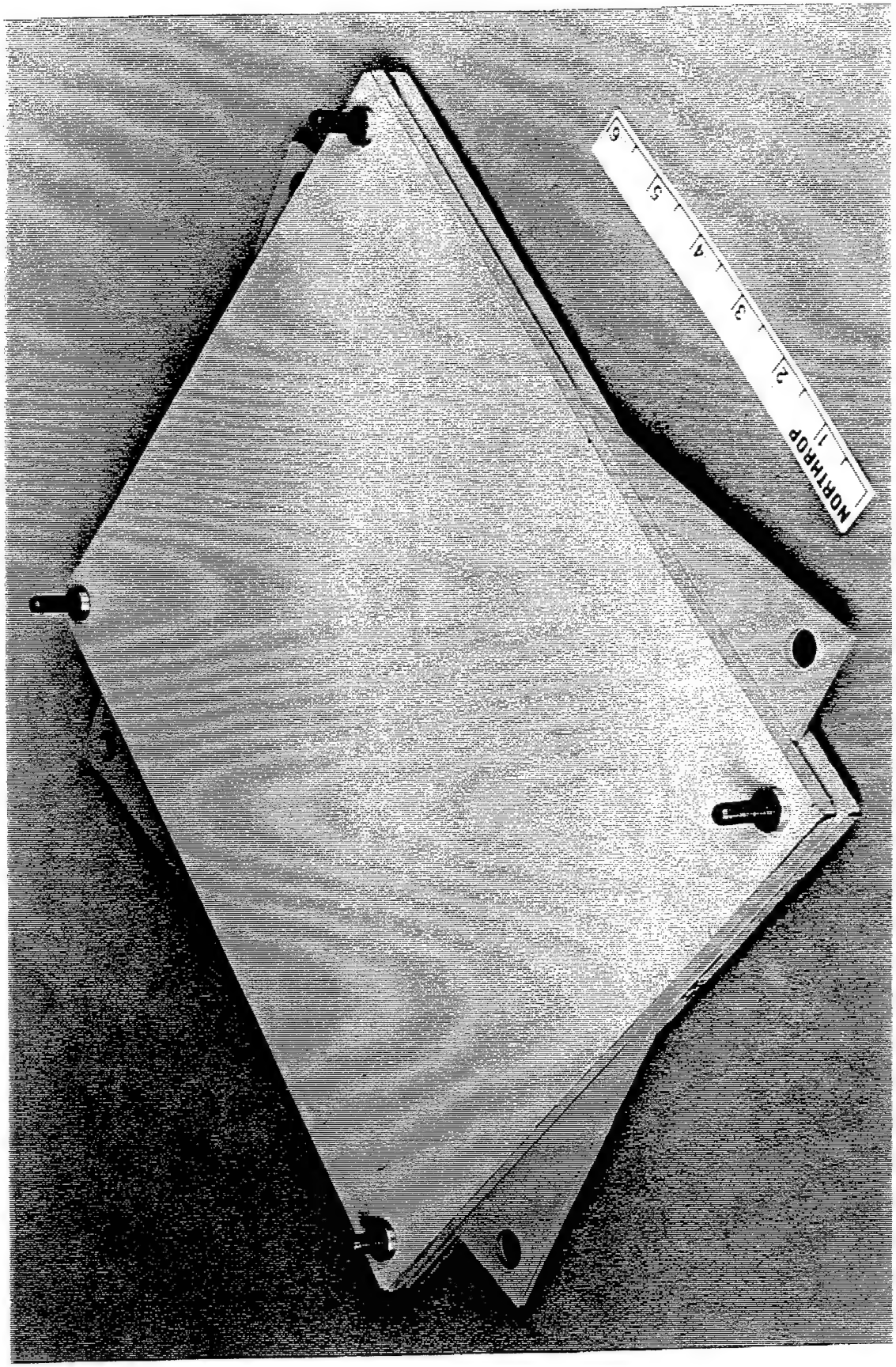
1. Clean the teflon coated plates so that they are free of any oils, fingerprints, chemical residues or debris.
2. Assemble the plates as shown on diagram.
3. Tighten the outside nut so that the plates are held together securely.
4. Tape around the perimeter of the assembled mold to seal. Form a taped "dam" at the top of the assembled plates using the tongue depressors for reinforcement.
5. Set mold aside until ready to pot.
6. Attach clean dry mixer blade to the mixer and tighten.
7. Open a can of 4952.
8. Insert mixer blade into the material.
9. Mix until all of the filler sediment has been resuspended in the resin. This will take at least 2 minutes and possibly more. Scrape the bottom and sides of the can to mix in any filler that has settled. The mixing is sufficient when no sediment is detected and the 4952N has taken on an even matte appearance with no evidence of shiny streaks or swirls.
10. Weigh out 3000 grams of 4952N to the nearest 0.1 gram into a clean tared inert container. Record the weight.
11. Into the same container, measure 4.5 grams (~270 drops) of Catalyst 50 dropwise with a clean inert dropper.
12. Mix well, scraping the bottom and sides of the container. The material should be mixed at least 2 minutes.
13. Deair the mixed material in a vacuum chamber at a vacuum of 10 torr minimum. Deair for 3 minutes. During the deairing process it may be necessary to break the vacuum to prevent the material from overflowing its container. When the level has dropped, draw vacuum again. Repeat as necessary. At the end of this time, outgassing should have ceased or dropped

to a rate of 1-2 bubbles per minute.

14. When the material has been completely deaired, remove the container from the vacuum chamber.
15. Place the prepared mold assembly in the vacuum chamber with the open top up.
16. Draw and hold vacuum for at least 2 minutes before filling.
17. Slowly fill the mold with the catalyzed 4952 N.
18. Allow the filled mold to deair until all outgassing is complete.
19. Break vacuum and remove the filled mold from the chamber.
20. Place the mold into an environmental chamber having a temperature of 32°C ± 5°C and a relative humidity of 70% ± 5% for 16 ± 1 hours.
21. Remove the mold assembly from the humidity chamber.
22. Disassemble the mold and remove the solidified sheet from the plated taking care not to tear them.
23. Place the rtv sheets in a humidity oven having a temperature of 65°C ± 5°C and a relative humidity of 75% ± 5% for 48 hours.
24. When the slabs have completed their cure, remove from the humidity oven and allow to cool to ambient temperature.
25. Cut test specimens with a sharp die.


1/2" DIAMETER
1/2"
1/2"
12"
10"




NORTHROP
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DESIGN AND MANUFACTURING GUIDELINES

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Test Method for Tensile Properties of Eccosil 4252N

Equipment:

Tensile Tester: MTS 810 Material Test System
Extensometer: MTS 632.12B-20
Grips: MTS Mechanical Wedge Action
Load Cell: 100 lb
Micrometer or Calipers

Other brands of equipment may be used if found to be equivalent. The grips must be capable of handling high elongation materials without allowing slippage.

Sample Preparation:

Specimens for testing are to be cut from cast silicone sheets of 0.125"+/- 0.010" thickness with a die conforming to ASTM D-412 Die C (Dogbone). The die must be sharp and free of nicks that may damage the specimen.

Specimens must be conditioned at 23°+/- 2° C and 50% +/- 5% RH for 48 minimum prior to testing. The specimens must be placed so that all sides of the specimen are in contact with the controlled atmosphere. Testing must take place within 24 hours after removing the samples from conditioning.

Measurement of specimen:

The thickness is to be measured at the center of the reduced section of the specimen. Due to the yielding nature of silicone care must be taken so as not to compress the specimen during measurement. Since even the sharpest die will not cut the silicone squarely , the width of the specimen is measured at the top and bottom of the specimen and the two measurements are averaged. This calculation is used to calculate the cross sectional area.

Test Conditions:

The atmospheric condition for testing should be the same as for conditioning, 23° +/- 2° C and 50% +/- 5% RH.

Procedure:

Place dogbone specimen in the grips of the testing machine, using care to adjust the specimen symmetrically to distribute the tension uniformly over the cross section. Adjust the grip separation to remove any slack in the sample. Attach the extensometer to the specimen. Set the rate of grip separation (crosshead speed) to 20" per minute. Any other speed may cause error and increase variability in elastomeric samples. Record the force and elongation at the time of rupture. Examine the break for any flaws or inclusions that might have influenced the break. If

any are present, the results of that particular specimen must not be used in further calculations.

Calculations

Tensile Strength = F / A

where F = Force at rupture
and A = Cross sectional area prior to testing

Tensile modulus is calculated by the use of linear regression in the area of the stress/strain curve where the curve is linear, the 5 - 30 % elongation range. The tensile modulus is the slope of this line.

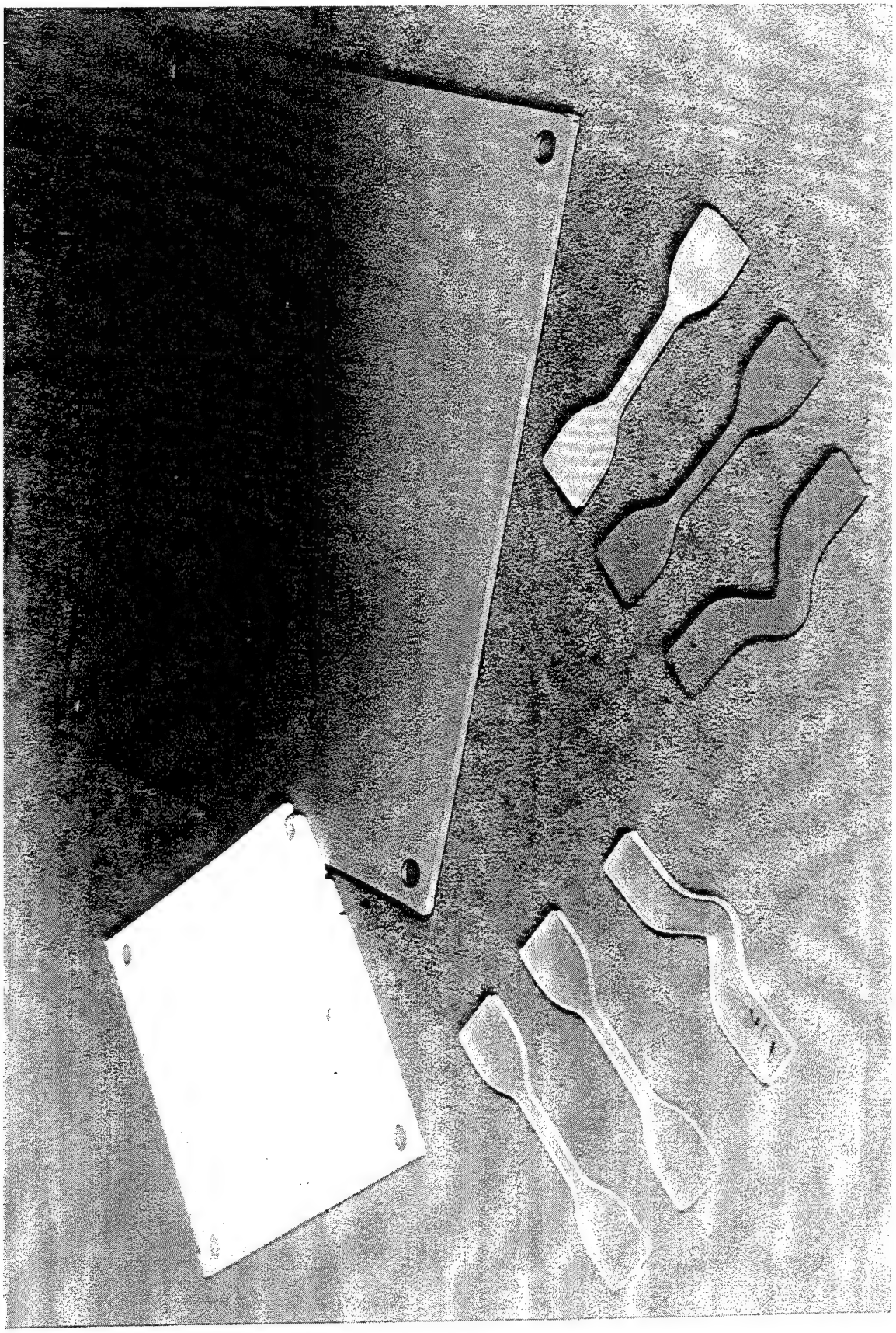
Report

The report shall include the following:

Results calculated as above
Failure mode and location of the failure
Description of the test equipment
Any Deviation from this test method

References

ASTM D 412 "Standard test method for Rubber Properties in Tension"
ASTM E 4 "Practice for Load Verification of Testing Machines"
Northrop method "Sample Preparation for 4952N"



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Test Method for Tear Strength of Eccosil 4252N

Equipment:

Tensile Tester: MTS 810 Material Test System
Grips: MTS Mechanical Wedge Action
Load Cell: 100 lb
Micrometer or Calipers

Other brands of equipment may be used if found to be equivalent. The grips must be capable of handling high elongation materials without allowing slippage.

Sample Preparation:

Specimens for testing are to be cut from cast silicone sheets of 0.125"+/- 0.010" thickness with a die conforming to ASTM D-624 Die C (unnicked 90°). The die must be sharp and free of nicks that may damage the specimen.

Specimens must be conditioned at 23°+/- 2° C and 50% +/- 5% RH for 48 minimum prior to testing. The specimens must be placed so that all sides of the specimen are in contact with the controlled atmosphere. Testing must take place within 24 hours after removing the samples from conditioning.

Measurement of specimen:

The thickness is to be measured at the center of the specimen. Due to the yielding nature of silicone care must be taken so as not to compress the specimen during measurement.

Test Conditions:

The atmospheric condition for testing should be the same as for conditioning, 23°+/- 26° C and 50% +/- 5% RH.

Procedure:

Place tear strength specimen in the grips of the testing machine, using care to adjust the specimen symmetrically in the direction of force to distribute the tension uniformly. Adjust the grip separation to remove any slack in the sample. Set the rate of grip separation (crosshead speed) to 20" per minute. Any other speed may cause error and increase variability in elastomeric samples. Record the force at the time of rupture. Examine the tear for any flaws or inclusions that might have influenced the break. If any are present, the results of that particular specimen must not be used in further calculations.

Calculations

Tear Strength = F / d

where F = Force at rupture
and d = specimen thickness

Report

The report shall include the following:

Results calculated as above
Failure mode and location of the failure
Description of the test equipment
Any Deviation from this test method

References

ASTM D-624 "Standard test method for Rubber Property-Tear Resistance
ASTM E 4 "Practice for Load Verification of Testing Machines"
Northrop method "Sample Preparation for 4952N"

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Detroit Testing Laboratory, Inc.
ESTABLISHED 1903
7111 E. Eleven Mile Warren, Michigan 48092 • P.O. Box 869 Warren, Michigan 48090-0869
(313) 754-9000 • (800) 837-1300 • FAX (313) 754-9045

REPORT NUMBER	CLIENT'S ORDER	DATE REC'D.	REPORT DATE
10424A	1221281	10-3-91	1-6-92

REPORT FOR

Northrop Corporation
Electronic Systems Division
600 Hicks Road
Rolling Meadows, IL 60008
Attn: Ms. Jeanne L. Beraduce
Phone: 708-259-9600 Ext. 6463

SUBJECT:

D-C Resistance (Volume Resistivity) of Insulating Materials, and A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials Tests performed on 36 samples supplied by Northrop Corporation.

TEST PERIOD:

From 11/4/91 To 12/24/91.

DESCRIPTION OF TEST SAMPLES:

The client submitted a total of 48 samples. The samples were identified by the client as:
1161 - 3B, 4A, 6C, 6D, 10A, 11C, 12D, 13B;
1165 - 2A, 3B, 4C, 4D, 10A, 11B, 12C, 12D;
1170 - 1A, 2B, 4C, 6A, 7B, 10C, 10D, 11D;
1177 - 2A, 4C, 7D, 10B, 10C, 11D, 15A, 16B;
1224 - 2A, 3B, 3D, 4C, 10A, 11B, 11D, 12C;
1250 - 2A, 3C, 6B, 6D, 11B, 12A, 16C, 16D.
Only 36 of them were tested.

TEST SPECIFICATIONS:

ASTM D 257 Standard Test Methods for D-C Resistance or Conductance of Insulating Materials.

ASTM D 618 Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing.

ASTM D 150 Standard Test Methods for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials.

TEST EQUIPMENT:

ITEM	MANUFACTURER	MODEL	SERIAL NUMBER	CAL TO DATE
High Resistance Meter	Hewlett Packard	4329A	2510J09653	1/24/93
Resistivity Cell	Hewlett Packard	16008A	2146J02263	N/A
Calliper	Mitutoyo	500-351	7090541	4/9/92
Electronic Timer	Micronta	63-879	N/A	N/A
Precision LCR Meter 20Hz-1MHz	Hewlett Packard	4284A	2940J02958	5/28/92
Dielectric Test Fixture	Hewlett Packard	16451B	2916J00111	N/A

TEST PROCEDURES:

VOLUME RESISTIVITY

All specimens were conditioned for a period of more than 40 hours in an environment of 23°C and a relative humidity of 50%. Each sample was placed into the resistivity cell and the cell door was closed. The test voltage was set to 500 VDC. The test voltage was applied to the sample for one minute before the resistance value was recorded. The following equation is used to derive the volume resistivity:

$$\rho = 19.6/t \times Rv$$

ρ :Volume resistivity in ohm-cm
t :Sample thickness in centimeters
Rv :Indicated volume resistance in ohms

DIELECTRIC CONSTANT

The Dielectric Test Fixture HP16451B was connected to the LCR Meter HP 4284A. Electrode adjustment and corrections (error compensation) were performed. Each sample was clamped between the micrometer electrodes (Contacting Electrode Method - Rigid Metal Electrode). The sample material was in close contact with electrodes. The 16451B micrometer reading -t- (as thickness of the sample) was recorded. Measurements of capacitance value were performed on each frequency (1kHz, 10kHz, 40kHz, 100kHz) and recorded as: Cp.

The following equation is used to derive the dielectric constant:

$$\varepsilon_r = (t \times C_p) / [\pi \times (d/2)^2 \times \varepsilon_o]$$

ε_r :Relative dielectric constant (Relative permittivity) of test material
t :Thickness of test material in meters
Cp :Equivalent parallel capacitance value in Farads
d :Diameter of test material in meters
ε_o :Dielectric constant of free space = 8.854×10^{-12} Farads/meter

TEST RESULTS:

See Appendix A and Appendix B - data sheets - for details.

DISPOSITION OF TEST SAMPLES:

Samples will be retained at DTL, Inc. for a period of 30 days after testing.

DETROIT TESTING LABORATORY, INC.

ARozenberg
Aron Rozenberg
Project Engineer

Alfredo Apolloni 18 Cm
Alfredo Apolloni
Test Operations Manager

File: VAX

ESTABLISHED 1903

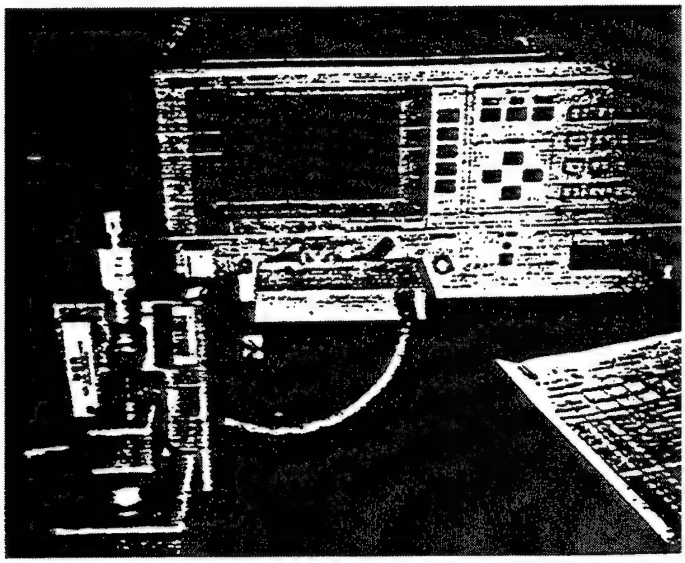
Detroit Testing Laboratory, Inc.

7111 E. ELEVEN MILE WARREN, MICHIGAN 48092 (313) 754-9000 (800) 837-1300 FAX (313) 754-9045

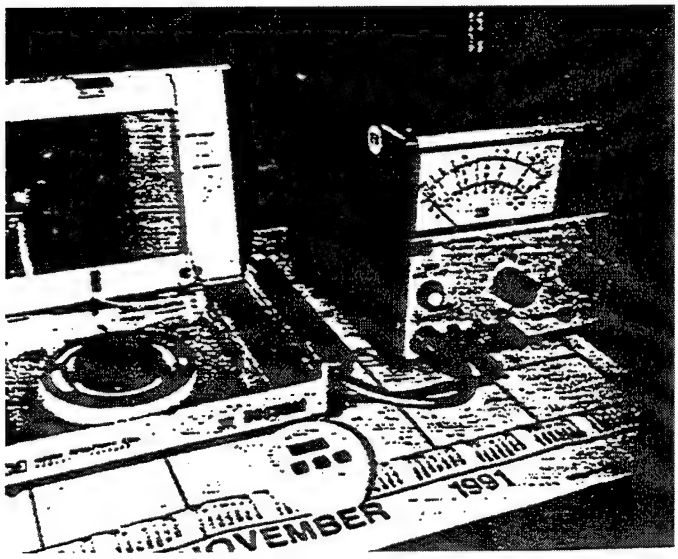
REPORT NUMBER 10424A

CLIENT NORTHROP CORPORATION DATE 1/6/92

SPECIMEN OF INSULATING MATERIALS CLIENT'S ORDER 1221281



10529A NORTHROP 12-20-91
DIELECTRIC CONSTANT TEST



10424A NORTHROP 11-5-91
VOLUME RESISTIVITY TEST

DESIGN AND MANUFACTURING GUIDELINES

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MATERIAL SPECIFICATION GUIDELINE

based on a proposal of the

TQ SHELF LIFE TEAM

OCTOBER, 1992

REV A 10/8/92

INTRODUCTION

The Shelf Life Materials Team proposed standardization of material specifications based on MIL-STD-490A "Specification Practices", Appendix XV "Type E, Material Specification". The Team recognized that a detailed specification may not be warranted or desirable in all cases (e.g., procurement and analysis of sample materials). However, the Team did recommend that a complete detailed specification be prepared in the following cases:

- All materials where required by contract
- Production materials deliverable along with the hardware to the Customer
- As-required production materials consumed in the process (i.e., non-deliverable) where the process is considered critical (i.e., impacts yields, costs, reliability) or where the volume of the material used and thus its overall cost is considered significant
- Costly developmental material where control is desirable to guarantee delivery and acceptance of materials conforming to critical specifications or other requirements
- Materials requiring tighter control related to environmental/safety issues

For other materials a less rigorous, less detailed specification may be appropriate. Selected paragraphs from the detailed specification may fulfill the requirement. However, the organization should still follow the outline of MIL-STD-490A and always address environmental/safety issues.

Additionally, the drawing type should be selected appropriately per MIL-STD-100E "Engineering Drawing Practices" as supported by ASME Y14.24M-1989 "Types and Applications of Engineering Drawings." The drawing types may be

- Vendor item drawings (formerly specification controls drawings)
- Selected item drawings
- Source control drawings

Be forewarned that application-specific detail and requirements embedded in a vendor item drawing may not be conveyed to the Supplier during the procurement cycle. Thus, there is the potential for Supplier initiated changes in material formulation, properties and testing which may prove unacceptable.

The following sections are based on the Team's recommendations and provide a guideline for preparing a detailed material specification.

GUIDELINES FOR DRAFTING MATERIAL SPECIFICATIONS

TITLE

A descriptive title should selected that fully identifies the material. Nomenclature, chemical description, application or other identifiers will help discriminate one material from the next amongst the thousands of 034's in the master listings. For example, there are dozens of materials described as "Insulating Compound, Electrical". 034-002983-001, 034-000373 and 034-000374 have the description "Epoxy" while 034-000471, 034-002799-001 and 034-000850 are among many described as "Adhesive".

1. SCOPE

1.1 SCOPE.

1.1 SCOPE. A general description of the material (i.e., RTV, epoxy, urethane, etc.), purpose or application (i.e., bonding, coating, encapsulation, etc.), and operating environment.

1.2 CLASSIFICATION.

1.2 CLASSIFICATION. (optional) Any relevant classifications or designations per mil spec or national standards.

2. APPLICABLE DOCUMENTS.

2.1 GOVERNMENT DOCUMENTS. A general statement of use of listed documents followed by a listing of the documents as follows:

Specifications:
- Federal
- Military
- Other government agency

Standards:
- Federal
- Military
- Other government agency

Drawings:
Other publications:

2.2 NON-GOVERNMENT DOCUMENTS. A general statement of use of listed comments followed by a listing of the documents as follows:

Specifications:
Standards:
Drawings:
Material Safety Data Sheets:
Other publications:

If applicable, the following statement about the availability of Technical Society or Association specifications should be included:

"REFERENCES TO SPECIFICATIONS AND STANDARDS FROM TECHNICAL SOCIETIES AND ASSOCIATIONS ARE GENERALLY AVAILABLE FOR REFERENCE FROM LIBRARIES. THEY MAY ALSO BE AVAILABLE FROM TECHNICAL GROUPS AND FEDERAL AGENCIES."

3. **REQUIREMENTS.**

3.1 **GENERAL MATERIAL REQUIREMENTS.**

3.1 GENERAL MATERIAL REQUIREMENTS. A statement summarizing the requirements specified in this section.

3.1.1. **CHARACTER OR QUALITY.**

3.1.1 QUALITY. A qualitative statement of the overall quality of the product.

3.1.2 **FORMULATION.**

3.1.2 FORMULATION. A quantitative description of formulation addressing tolerances and control limits. For a multiple component system, include the mix ratio, cure schedule, and any pertinent processing requirements. For all systems (i.e., one part, two part, finished product, etc.), include material types and/or component quantities of which the product is made if such information is available and does not infringe on the proprietary rights of the Supplier.

Where appropriate the following paragraphs may be added:

3.1.2.1 Cure Schedule(s)
3.1.2.2 Pot Life
3.1.2.3 Drying Schedule

3.1.3 **PRODUCT CHARACTERISTICS.**

3.1.3 MATERIAL CHARACTERISTICS. Specific dimensions; physical, chemical and mechanical properties of the material and performance characteristics. The information is of a reference nature and thus tolerances need not be identified here. Examples: surface finish, color.

3.1.4 **CHEMICAL, ELECTRICAL, AND MECHANICAL PROPERTIES.**

3.1.4 MATERIAL PROPERTIES. Examples: Composition, chemical concentration, hardness, tensile or shear strength, elongation, thermal expansion, electrical resistivity, dielectric constant, viscosity, pot life, solids content, etc. Wherever possible define properties by associated test methods (e.g., ASTM tests) and specify tolerances. Focus on critical properties rather than all properties. Consider availability of test equipment at NC-ESD or outside test labs capable of conducting or replicating specified tests to evaluate properties.

3.1.5 **ENVIRONMENTAL CONDITIONS.**

3.1.5 ENVIRONMENTAL CONDITIONS. Environmental conditions which the materials must withstand. This includes climate, shock, vibration, noise, etc. Consider storage, assembly processes, environmental stress screening, burn-in and the operating environment. Consider that the material may have to serve a multiplicity of applications. Reference appropriate mil specs.

3.1.6 STABILITY.

3.1.6 STABILITY. Requirements for shelf life, aging, etc. Cite 093-006159 "Storage and Shelf Life Requirement for Perishable Materials". This document calls out 099-012847 "Shelf Life List for Time/Temperature Sensitive Material" administered by RAL. Other documents which may be required: IP 2.8.7.14 "Operations - Material Storage and Control". This document describes the Operations Departments's policies concerning the storage and control of incoming or returned materiel, including material which is limited by time and environmental conditions.

3.1.7 TOXIC PRODUCTS AND SAFETY

3.1.7 HAZARDOUS AND TOXIC MATERIALS.

Identify specific safety requirements from the Material Safety Data Sheet or provide instructions such as:

Personal Protective Equipment- Eye Wear, Gloves, Respirator, etc.
Ventilation- General or specific Exhaust
Primary Health Hazards- Inhalation, skin contact, flammability, etc.
Disposal Method- Normal Trash, Hazardous Waste, Special Waste, etc.

The Environmental & Safety organization can provide help in generation of this section. As a minimum, the following statement should be used.

"THE PRODUCTS SUPPLIED TO THIS DOCUMENT POSE POTENTIAL HEALTH OR SAFETY HAZARDS. APPROPRIATE CARE SHALL BE EXERCISED IN HANDLING THE PRODUCTS IN ACCORDANCE WITH THE MATERIAL SAFETY DATA SHEETS (MSDS) SUPPLIED BY THE MANUFACTURER, INSTRUCTIONS OR PROCEDURES OF THE MANUFACTURER OR SUPPLIER, THE USER'S SUPERVISION AND THE ENVIRONMENTAL AND SAFETY ORGANIZATION."

Where appropriate the following shall be added:

"THE RESIDUAL MATERIAL LEFT OVER FROM THE USE OF THIS PRODUCT(S) ARE CLASSIFIED AS HAZARDOUS OR SPECIAL WASTE AND MUST BE DISPOSED OF AT THE DISCRETION OF THE ENVIRONMENTAL AND SAFETY ORGANIZATION."

3.1.8 IDENTIFICATION AND MARKING.

3.1.8 MARKING. Requirements for the identification coding of the material. The following should be used as appropriate. Cite MIL-STD-130 as appropriate.

A. NORTHROP ESD PART NUMBER.
B. MANUFACTURER'S PART NUMBER.
C. MANUFACTURER'S LOT OR BATCH NUMBER.
D. NAME OF MANUFACTURER.
E. CAGE CODE (IF APPLICABLE).
F. DATE OF MANUFACTURE.
G. PRECAUTIONARY HANDLING (IF APPLICABLE).
H. STORAGE TEMPERATURE AND HUMIDITY (IF APPLICABLE).
I. PRIMARY HAZARD- FLAMMABILITY, CORROSIVITY, REACTIVITY AND HEALTH.

3.1.9 **WORKMANSHIP.**

3.1.9 WORKMANSHIP. General statement covering features that can be verified by visual examination. Requirements that are incident to the manufacture or processing of the material. In addition, the following general statement is frequently appropriate:

"MATERIAL SHALL BE FORMULATED, HANDLED, PACKAGED, AND STORED IN A MANNER TO PREVENT CONTAMINATION OF THE PRODUCT FROM FOREIGN MATERIALS OR EXPOSURE TO ENVIRONMENTAL CONDITIONS THAT WILL DEGRADE THE MATERIAL."

More specific information may be appropriate for specific applications.

3.2 **QUALIFICATION INSPECTION.**

3.2 QUALIFICATION INSPECTION. This paragraph cites the necessity for qualification and ties directly with Section 4.0 "Quality Assurance Provisions". Qualification may result from a design review or test data review. Where performance qualification is required, whether on a one-time basis or a periodic basis, to achieve approval, proof of producibility, assessment of production or other reason, provision for such qualification testing shall be stated in this paragraph. Requirements shall be included which state the conditions for testing, the time (program phase) of testing, period of testing, number of units to be tested, and other requirements relating to qualification or requalification. Where it is essential that a preproduction or periodic production sample or a pilot lot be tested for approval prior to or during regular production on a contract or order, the requirements shall be specified in this section.

4. **QUALITY ASSURANCE PROVISIONS.**

4.1 **RESPONSIBILITY FOR INSPECTION.**

Where NC-ESD has responsibility for inspections, ensure that the responsible organization has or has access to the appropriate inspection/test equipment meeting the inspection standards.

The statements in the following sub-paragraphs may be appropriate:

4.1 RESPONSIBILITY FOR INSPECTION.

4.1.1 UNLESS OTHERWISE SPECIFIED IN THE CONTRACT OR PURCHASE ORDER, THE SUPPLIER SHALL BE RESPONSIBLE FOR THE PERFORMANCE OF ALL INSPECTION REQUIREMENTS AS SPECIFIED HEREIN. EXCEPT AS OTHERWISE SPECIFIED IN THE CONTRACT OR PURCHASE ORDER, THE SUPPLIER MAY USE HIS OWN FACILITIES OR ANY COMMERCIAL LABORATORY ACCEPTABLE TO THE CONTRACTOR. THE CONTRACTOR RESERVES THE RIGHT TO PERFORM ANY OR ALL OF THE INSPECTIONS SET FORTH HEREIN WHERE SUCH INSPECTIONS ARE DEEMED NECESSARY TO ASSUME THAT THE SUPPLIES AND SERVICES CONFORM TO THE PRESCRIBED REQUIREMENTS.

4.1.2 INSPECTION RECORDS SHALL BE KEPT COMPLETE AND AVAILABLE TO THE CONTRACTOR IN ACCORDANCE WITH THE CONTRACT OR PURCHASE ORDER. THE RECORDS SHALL CONTAIN ALL DATA NECESSARY TO DETERMINE COMPLIANCE WITH THE REQUIREMENTS SPECIFIED HEREIN.

4.2 SPECIAL TESTS. A statement that describes the tests that are required to qualify and accept the material. A table is very effective for this purpose which would be referenced with the following statement:

"THE TESTS SHALL BE CLASSIFIED IN ACCORDANCE WITH TABLE --."

4.2.1 QUALIFICATION TESTS. Describe the purpose, description, and tolerances of the tests. Identify when these tests are to be performed per the requirements referenced in 4.2. The following statement is usually appropriate:

"THESE TESTS ARE TO DETERMINE COMPLIANCE WITH THE TECHNICAL REQUIREMENTS OF THIS SPECIFICATION. THE TESTS SHALL BE PERFORMED BEFORE SHIPMENT OF THE INITIAL LOT OF MATERIAL. TESTS SHALL BE PERFORMED TO THE REQUIREMENTS OF TABLE -- AND TEST DATA SHALL BE SUPPLIED WITH THE SHIPMENT."

4.2.2 ACCEPTANCE TESTS. Describe the type and purpose of these tests, when these tests are to be performed to test to the requirements referenced in 4.2. The following typical statement can be used:

"THESE TESTS ARE TO DETERMINE COMPLIANCE WITH THE TECHNICAL REQUIREMENTS OF THIS SPECIFICATION FOR EACH SHIPMENT AND LOT. THESE TESTS SHALL BE PERFORMED BEFORE EACH SHIPMENT AND BEFORE EACH LOT OF MATERIAL. TESTS SHALL BE PERFORMED TO THE REQUIREMENTS OF TABLE -- AND TEST DATA SHALL BE SUPPLIED WITH THE SHIPMENT."

Describe procedures specifying what actions are to be taken if there are test rejections.

4.3 QUALITY CONFORMANCE INSPECTION.

4.3 QUALITY CONFORMANCE INSPECTION. A description that delineates all inspections and tests required on a repetitive lot-by-lot basis. Test and inspection methods are to be specified. Include as much detail about the tests as possible. Note: some generalized test methods (e.g., tensile strength) have many delimiters and variables which must be specified to allow replication.

Where appropriate the following paragraphs may be included addressing Supplier reporting requirements:

4.4 REPORTS

4.4.1 Before implementation, the supplier shall report any modification of the material, change in the method of manufacture, or change in the manufacturing site to contractor to evaluate the need for requalification.

4.4.2 Unless otherwise specified, the supplier of the material shall furnish, with each shipment, x copies of a report that contains the results of tests for the required properties of each lot in the shipment. The report shall include the purchase order number, material specification number and revision letter, material designation, size, and quantity. The supplier that performs the work shall be the only organization to issue the report.

5. PREPARATION FOR DELIVERY.

5.0 PREPARATION FOR DELIVERY. All applicable requirement for preservation, packaging, and packing as well as markings of packages and containers are specified. Perishable materials should have specific supplier shipping advance notification requirements.

The following paragraphs may be appropriate:

5.1 GENERAL REQUIREMENTS. All materials shall be preserved and either wrapped or packaged to ensure protection from contamination, environmental deterioration and physical damage during normal handling, transportation, and storage. Materials shall be stored indoor in a dry area. Each unit and shipping containers shall be marked according to the requirements of this specification.

5.2 PACKAGING MATERIALS. Materials used in preservation, packaging, and packing shall be per standard commercial practice and in compliance with applicable rules and regulations.

5.3 PREPARATION. The product shall be prepared for shipment per standard commercial practice and in accordance with applicable rules and regulations that pertain to the handling, packaging, and transportation of the product. The product shall also be prepared to ensure carrier acceptance and safe delivery at the lowest rate to the delivery point.

5.3.1 PRESERVATION AND PACKAGING. All material shall be preserved and packaged to ensure protection from contamination, environmental deterioration and physical damage during normal handling, transportation, and storage.

5.3.2 PACKING. The material shall be packed in a container that shall be acceptable for safe transportation by common carriers.

5.3.3 MARKING FOR SHIPMENT. In addition to the requirements of 3.1.8, the following information shall be identified directly on the exterior package.

A. Purchase Order Number
B. Quantity of material shipped
C. Lot number and date of manufacture

6. NOTES.

6.0 NOTES. Include special notes as appropriate.

The following sections may be appropriate:

6.1 Intended use

6.2 Suggested source(s) of supply

6.3 Definitions

6.4 Ordering data

DESIGN AND MANUFACTURING GUIDELINES

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PROCEDURAL DETAILS

	Pages
2.0 Silicones, Introduction 2.8 Material Specification	2.1-48 to 2.1-57

2.0 Dock-To-Stock / Consistency Awareness

A traditional Northrop Grummman specification for Silicone rubber encapsulant was updated in a relatively simple manner to serve the added function of a Dock-To-Stock document. After extensive electrical, mechanical and environmental testing of various silicone rubber parameters, two measures of silicone - Tear Strength and Compressive Modulus - were considered both meaningful and cost effective as indicators of quality and reliability. Round robin testing between Northrop Grumman, Emerson Cuming/Grace Specialty Poyymers (the silicone supplier) and third party testing laboratories combined to allow the establishment of both specification limits and Statistical Process Control (SPC) limits for these two parameters. Specification 034-000698 is the resultant purchase document. Note that specific acceptance test information from each batch of material is required and that Tear Strength and Compressive Modulus SPC limits will be updated with information from every group of five batches of material. Mechanics of the Dock-To-Stock agreement are called out in the purchase order and allow for direct stocking (and/or distribution to the production floor) of the incoming material after inspection of customer supplied acceptance test information. The SPC limits allow trend analysis so that problems can be identified early. These limits are tighter than the specification limits but cannot be used for material rejection.

Rev. D 10/6/95

TITLE

INSULATING COMPOUND, ELECTRICAL, THERMALLY CONDUCTIVE, CONDENSATION CURE, TWO-PART, RTV SILICONE BASED

1. SCOPE

1.1 **SCOPE -** This drawing covers the detailed requirements for RTV silicone used for encapsulating, potting and embedding electrical devices operating at -55 degress Centigrade to +175 degrees Centigrade.

2. APPLICABLE DOCUMENTS

2.1 **GOVERNMENT DOCUMENTS -** The following documents form a part of the specification to the extent specified herein. Issues of these publications current at the time of bid or proposal shall be used. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

2.1.1 **STANDARDS**

Military Standards

MIL-STD-129 Marking for Shipment and Storage

2.2 **NON-GOVERNMENT DOCUMENTS -** The following documents form a part of the specification to the extent specified herein. Issues of these publications current at the time of bid or proposal shall be used. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

Specifications (Northrop Electronics and Systems Integration Division (EWS-RM), Rolling Meadows, Illinois):

093-006159 - Storage and Shelf Life Requirements for Perishable Materials

324-000547 - Preparation & Application, Rubber, Silicone RTV, 034-000698

Standards:

American Society for Testing and Materials (ASTM)

ASTM D 149 - Test for Dielectric Breakdown Voltage and

Dielectric Strength of Electrical Insulating Materials at Commercial Power Requirements

ASTM D 150 - Method of Test for A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials

ASTM C 177 - Thermal Conductivity of Materials by Means of Guarded Hotplate

ASTM D 257 - Tests for Electrical Resistance--Volume Resistivity

ASTM D 412 - Method of Tension Testing of Vulcanized Rubber

ASTM F 433 - Evaluating Thermal Conductivity of Gasket Materials

ASTM D 575 - Standard Test Methods for Rubber Properties in Compression

ASTM D 618 - Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing

ASTM D 624 - Standard Test Methods for Rubber Property - Tear Resistance

ASTM D 638 - Standard Test Method for Tensile Properties of Plastics

ASTM D 647 - Specification for Molds for Test Specimens of Plastic Molding Materials

ASTM D 696 - Coefficient of Linear Thermal Expansion of Plastics

ASTM D 1622- Standard Test Method for Apparent Density of Rigid Cellular Plastics

ASTM D 2520- Complex Permittivity (Dielectric Constant) Of Solid Electrical Insulating Materials At Microwave Frequencies and Temperatures to 1650°C.

3. REQUIREMENTS

3.1 **General Material Requirements -** The material furnished per this specification shall be tested and shall pass the qualification tests specified herein. After qualification, any modification of the material, change in the method of manufacture, or change in manufacturing site may be cause for requalification.

3.1.1 **QUALITY -** The encapsulant components shall be of uniform quality and consistency, homogeneous, and free of agglomerates and foreign materials.

3.1.2 **FORMULATION**

3.1.2.1 Standard Mix Ratio - Refer to 324-000547, Table 1.0.

3.1.2.2 Special Mix Ratio - Mix ratio for the testing of pot life/hardness only shall be 0.08 to 0.12 percent catalyst by weight.

3.1.2.3 Cure Schedule

3.1.2.3.1 Standard Cure Schedule - Refer to 324-000547 paragraph 3.3.7.

3.1.2.3.2 Special Cure Schedule - Cure schedule for the hardness testing of samples prepared per 3.1.2.2 shall be as follows:

a. Cure at 30 degrees to 40 degrees Centigrade and 60 to 80 percent relative humidity for 16 to 18 hours.

b. Cure at 60 degrees to 70 degrees Centigrade and 60 to 80 percent relative humidity for 4-6 hours

3.1.3 Material Characteristics - The material shall be furnished as a two-part, RTV silicone system.

3.1.4 Material Properties - The material properties shall be in accordance with the requirements listed below.

3.1.4.1 *Tear Strength

When tested per ASTM D 624, using the Die-C sample cut from a 1/8th inch thick slab and pulled at 20 inches per minute, the mean tear strength of a sample size of at least 10 pieces shall be within the limits of 23 to 41 pounds per inch of thickness (ppit).

3.1.4.2 *Compressive Modulus

When tested per ASTM D 575, method A, using a 1.125 inch diameter by 0.5 inch thick sample configuration and a head speed of 1/2 inch per minute, the mean compressive modulus of a sample size of at least 10 pieces shall be within the limits of 560 to 1414 lbs. per square inch of cross-section (psi).

* These parameter values will be reviewed and updated every five batches of material.

3.1.4.3 Pot Life

The pot life of the material shall meet the criteria as depicted by Figure 1 when mixed per 3.1.2.2.

3.1.4.4 Hardness

Hardness shall be within the limits of 55 to 75 Shore A per ASTM D 2240 when mixed per 3.1.2.2 and cured per 3.1.2.3.2.

3.1.4.5 Viscosity

The viscosity of Part A shall be 22,000 to 32,000 centipoise using a Brookfield Viscometer Model HBT T-Bar spindle #5 at 20 revolutions per minute.

3.1.4.6 Dielectric Constant

The dielectric constant of this material shall be within the limits of 4.66 to 5.42 when measured at 10 kilohertz at 25 degrees Centigrade in accordance with ASTM D 150 or shall be within the limits of 3.5 to 6.0 when measured at 8.6 gigahertz in accordance with ASTM D 2250.

3.1.4.7 Dielectric Strength

The dielectric strength at 25 degrees Centigrade shall be a minimum of 254 volts (rms) per mil. The testing shall be performed in accordance with ASTM D 149 using 500 volts/second rise time.

3.1.4.8 Thermal Conductivity

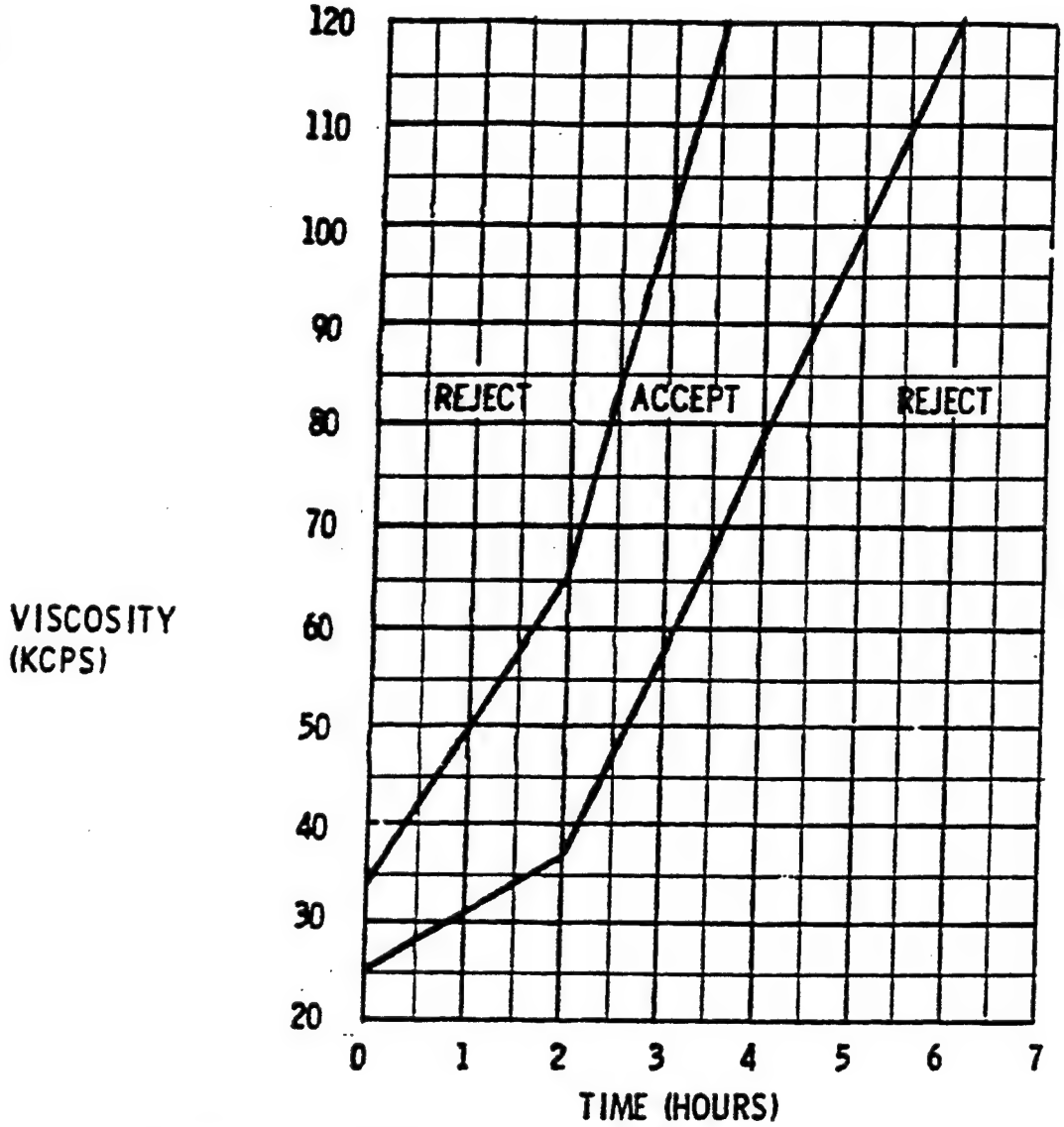
The thermal conductivity at 25 degrees Centigrade shall be a minimum of 5.7 Btu-in./ft^2-deg. F - hr. when measured in accordance with ASTM C 177 or shall be a minumum of 4.8 Btu-in./ft^2-deg. F - hr. when measured in accordance with ASTM F 433.

3.1.4.9 Tensile Strength

The tensile strength at 25 degrees Centigrade shall be a minimum of 330 pounds per square inch (psi) when measured in accordance with ASTM D 412.

3.1.4.10 Coefficient of Thermal Expansion

The coefficient of thermal expansion (over the temperature range of -75°C to +125°C) shall be within the limits of 140 to 275 microinches (10^{-6})



ALL DATA TAKEN WITH BROOKFIELD VISCOSIMETER
MODEL HBT SPINDLE 5, 20 RPM
ROOM TEMPERATURE 50% MAXIMUM RH
READING AT T = 0. TAKEN IMMEDIATELY AFTER
CATALYST ADDITION AND DEAIRING OF SAMPLE BATCH.

FIGURE 1. ACCEPT/REJECT CRITERIA

SIZE	FSCM NO.	DWG NO.	REV
A	26916	034-000698	D
SCALE NONE		SHEET 5	

8411 (11/78) (156-000817C)

per inch per degree Centigrade. Expansion should be measured in accordance with ASTM D 696.

3.1.4.11 Volume Resistivity

The volume resistivity at +100 degrees Centigrade shall be a minimum of 10^{11} ohms-centimeter when measured in accordance with ASTM D 257.

3.1.4.12 Specific Gravity

The apparent overall density (specific gravity) at 23°C of part A shall be within the limits of 2.05 to 2.4 when measured in accordance with ASTM D 1622 or equivalent test. The filled shipping container may be used as a single test specimen.

3.1.5 General Information

The following table lists material properties for information purposes only:

Property	Value
Elongation, %	100
Heat Endurance °C	260
Water Absorption, %	0.2
Loss Tangent @ 8.6 GHz.	0.01
Dielectric constant @ 8.6 Ghz.	5.2
Stiffening temperature °C (Crystalline melt)	-53
Glass Transition °C	-126

3.1.6 Stability

3.1.6.1 Shelf Life - Shelf life requirements shall be in accordance with 093-006159, Classification Type I. The material shall meet the requirements of this document for the entire shelf life period as specified in 093-006159. The material may be resampled and retested using Production Acceptance Test Procedures for shelf life extension. Material lot samples which fail the retest shall be rejected.

3.1.6.2 Material Storage and Control shall be in accordance with IP 2.8.7.14 "Operations - Material Storage and Control" (this I.P. only governs the contractor's Production Operations Department) and

093-006159 "Storage and Shelf Life Requirements for Perishable Materials."

3.1.7 Hazardous and Toxic Materials

The products supplied to this document pose potential health or safety hazards. Appropriate care shall be exercised in handling the products in accordance with the material safety data sheets (MSDS) supplied by the manufacturer, instructions or procedures of the manufacturer or supplier, the user's supervision and the environmental and safety organization.

The residual materials left over from the use of this product(s) may be classified as hazardous or special waste and must be disposed of at the discretion of the environmental and safety organization.

3.1.8 Identification and Marking - In addition to any special marking required by the contract or purchase order, each unit and shipping container shall be marked in accordance with MIL-STD-129 and the requirements of the Interstate Commerce Commission. Marking shall also include the following:

A. Northrop EWS part number
B. Manufacturer's part number
C. Manufacturer's lot or batch number
D. Name of Manufacturer
E. Cage Code (if applicable)
F. Date of manufacture
G. Precautionary handling
H. Storage temperature and humidity (if applicable)
I. Primary hazard - flammability, corrosivity, reactivity and health

3.1.9 Workmanship - Material shall be formulated, handled, packaged, and stored in a manner to prevent contamination of the product from foreign materials or exposure to environmental conditions that will degrade the material.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

4.1.1 Unless otherwise specified in the contract or purchase order, the supplier shall be responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or purchase order, the supplier may use his own facilities or any commercial laboratory acceptable to the contractor. The contractor reserves the right to perform any or all of the inspections set forth herein

where such inspections are deemed necessary to assure that the supplies and services conform to the prescribed requirements.

4.1.2 Inspection records shall be kept complete and available to the contractor in accordance with the contract or purchase order. The records shall contain all data necessary to determine compliance with the requirements specified herein.

4.2 Classification of Tests - The tests shall be classified in accordance with Table I.

TABLE I. CLASSIFICATION OF TESTS

Test	Requirement Paragraph	Qualification	Acceptance
Quality	3.1.1,3,9	X	X
Tear Strength	3.1.4.1	X	X
Compressive Modulus	3.1.4.2	X	X
Pot Life	3.1.4.3	X	X
Hardness	3.1.4.4	X	X
Viscosity	3.1.4.5	X	X
Dielectric Constant	3.1.4.6	X	
Dielectric Strength	3.1.4.7	X	
Thermal Conductivity	3.1.4.8	X	
Tensile Strength	3.1.4.9	X	
Coefficient of Thermal Expansion	3.1.4.10	X	
Volume Resistivity at +100 degrees Centigrade	3.1.4.11	X	
Specific Gravity	3.1.4.12	X	

4.2.1 Qualification Tests - These tests are to determine compliance with the technical requirements of this specification. The tests shall be performed before shipment of the initial lot of material. Test shall be performed to the requirements of Table I and test data (4.2.6) shall be supplied with the shipment.

4.2.2 Acceptance Tests - These tests are to determine compliance with the technical requirements of this specification for each shipment and lot. These tests shall be performed by the supplier before each shipment and of each lot of material. Tests shall be performed to the requirements of Table I and test data (4.2.6) shall be supplied with each shipment.

4.2.3 Sampling - A sample, consisting of a sufficient amount of material necessary for the required tests (4.2)(shall be selected at random from each lot of material.

4.2.4 Rejection - Any material not meeting the requirements

of this specification shall be rejected.

4.2.5 Retest - Material rejected may be retested once. For retest, sample twice the number of units, if possible. If any retest specimen fails to meet the requirements, the entire lot shall be rejected.

4.2.6 Reports - With each shipment, unless otherwise specified, the material supplier shall furnish the contractor with three copies of a test report. The report shall contain the results of tests made on the product, which shall determine conformance to the applicable test requirements of this document. The report shall also include:

A. This document number and revision letter
B. Purchase order number
C. Manufacturer's name
D. Manufacturer's part number
E. Manufacturer's lot or batch number
F. Manufacturer's date of manufacture
G. Quantity of material shipped

5.0 PREPARATION FOR DELIVERY

5.1 GENERAL REQUIREMENTS

All materials shall be preserved and either wrapped or packaged to ensure protection from contamination, environmental deterioration and physical damage during normal handling, transportation, and storage. Materials shall be stored indoor in a dry area. Each unit and shipping containers shall be marked according to the requirements of this specification.

5.2 PACKAGING MATERIALS

Materials used in preservation, packaging and packing shall be per standard commercial practice and in compliance with applicable rules and regulations.

5.3 PREPARATION

The product shall be prepared for shipment per standard commercial practice and in accordance with applicable rules and regulations that pertain to the handling, packaging, and transportation of the product. The product shall also be prepared to ensure carrier acceptance and safe delivery at the lowest rate to the delivery point.

5.3.1 Preservation and Packaging

All material shall be preserved and packaged to ensure protection from contamination, environmental

deterioration and physical damage during normal handling, transportation, and storage.

5.3.2. Packing

The material shall be packed in a container that shall be acceptable for safe transportation by common carriers.

5.3.3 Marking for Shipment

In addition to the requirements of 3.1.8, the following information shall be identified directly on the exterior package.

A. Purchase order number
B. Quantity of material shipped
C. Lot number and date of manufacture

6.0 NOTES

6.1 IDENTIFICATION - Only the item described on this drawing when procured from the vendor(s) listed herein is approved by Northrop EWS-RM, Rolling Meadows, Illinois, for use in the application(s) specified herein. A substitute item shall not be used without prior approval by Northrop EWS-RM or by cognizant procuring activity.

Identification of the approved source(s) of supply herein is not to be construed as a guarantee of present or continued availability as a source of supply for the item(s) described on the drawing.

6.2 APPROVED SOURCE(S) OF SUPPLY

Northrop EWS-RM Part No.	Manufacturer	Manufacturer's Part No.	Cage Code
034-000698	Emerson & Cuming, Inc. Woburn, MA	Eccosil 4952N/ Catalyst 50	04552

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

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3.1 Characterization And Processing Of Selected Materials

Figure 1 lists sixteen tests that are recommended for a comprehensive evaluation of an epoxy or urethane that is being considered as a possible high voltage encapsulant. These tests were performed on the thirteen materials listed in figure 1 as part of the MANTECH HVPS program. The test procedures are from Military Specifications (Mil-Specs) and/or the American Society for Testing Materials (ASTM) specifications. Sample preparation and cure schedules for the materials are shown in Figure 2. Test results are detailed in the final program report. A number of the materials were used in Model Test Structures to determine their performance in actual operating environments. Details of those evaluations the are in Volume 3 to these guidelines.

MATERIALS
SCOTCHCAST 280
SCOTCHCAST 281
SCOTCHCAST MR283 F025
SCOTCHCAST MR283 F100
PR 1665
RICOTUFF LV (NO POSTCURE)
RICOTUFF LV (POSTCURED)
EPON 825/HV
STYCAST 2651
STYCAST 2850 FT
HRG-3/A2
HRG-3/A0
URALANE 5753

TESTS
DIELECTRIC STRENGTH
DIELECTRIC CONSTANT (1 kHz – 1 MHz)
VOLUME RESISTIVITY
DISSIPATION FACTOR (1 kHz – 1 MHz)
HARDNESS
THERMAL CONDUCTIVITY
TENSILE STRENGTH
ELONGATION
LAP-SHEAR
T-PEEL
Td
Tg
CTE
WORK LIFE
VISCOSITY
IZOD IMPACT

Figure 1

MATERIAL	MIX RATIO (PBW)	CURE SCHEDULE		SPECIAL HANDLING
		TEMPERATURE (°F)+	TIME (HOURS)*	
SCOTCHCAST MR 283 F025	5 TO 1	167	36	WARM PART A AND B SEPARATELY TO NO MORE THAN 140°F HIGH SPEED MIXING 1000-1600 RPM
SCOTCHCAST MR 283 F100	5 TO 1			
SCOTCHCAST 280	2 TO 3	150	24	WARM PART A AND B SEPARATELY TO NO MORE THAN 140°F
SCOTCHCAST 281	2 TO 3			
STYCAST 2850 FT (CATALYST II)	100 TO 8	160	2	NONE
STYCAST 2651	100 TO 8			NONE
EPON 825/HV	100 TO 18	160 250	16 4	DECRYSTALLIZE EPON 825 AT 160°F
PR 1665	36 TO 100	75 180	24 16	DECRYSTALLIZE PART A AT 240-260°F, AND PART B AT 120-140°F. COOL BEFORE USING
HRF-3/A0	100 TO 24	160 250	16 4	NO RESIN PRE-HEATING
HRG-3/A2	100 TO 60			
URALANE 5753	10 TO 2	160 200	16 2	NONE
RICOTUFF LV (NO POSTCURE)	200 TO 100 TO 4	160	4	PRE-HEAT PART A AND B AT 160°F BEFORE MIXING WITH PART C
RICOTUFF LV (POSTCURED)	200 TO 100 TO 4	160 212	4 1	
EPOTEK XK/5022-86	100 TO 200	75 302	24 2	NONE

NOTE: Unless otherwise noted, processing procedure consisted of mixing part A and part B by hand until homogeneous. Pre-heat the mixture at 160°F, degass and pour in pre-heated mold (~160°F).

+Tolerances = ±3°F
*Tolerances = ±5 min for cure times ≤4 hrs, ±15 min for >4 hr

Figure 2

DESIGN AND MANUFACTURING GUIDELINES

FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 3

PROCEDURAL DETAILS

	Page
3.0 Epoxies/Urethanes	
3.2 Stress Aging	3.2-2

3.2 Stress Aging

Volume constrained applications of encapsulants create substantial internal stresses when subjected to the temperature extremes of a military environment. The stresses are often relieved via fracturing of the encapsulant and/or damage to the surrounding materials and components. To determine the fracture toughness of Emerson & Cuming Stycast 2651MM epoxy, a stress aging program was conducted by Dr. Stephen Carr at Northwestern University. This program was part of a broader requirement to assess the extent of cure in epoxies. Details of this latter program are included in the final program report.

Figures 1 and 2 show test specimen and test fixture details to measure fracture toughness. The test specimens are characterized by wedge shaped ends for gripping in the test fixture. The fixture permits stacking of several test samples. Once loaded, the samples can be subjected to a pre-selected tensile load. The entire assembly can then be temperature cycled to provide both tensile and temperature stresses simultaneously. The critical stress required to propagate a crack is formulated and illustrated in Figure 3. Figure 4 provides further details and plots several data points from samples with different notch depths. Figure 5 gives the results of one set of experiments (at 80C) and shows both the rapid initial loss of toughness with aging and the affects on ageing when stress is applied. Further experiments proved that fracture toughness also decreases with increased temperatures; thus, a matrix of temperature and applied stress can be developed to characterize the aging properties of the test specimen.

Given a properly established group of specimens and test conditions, this technique for measuring fracture toughness can be a useful tool to compare formulations and cure schedules of a single material or of various materials.

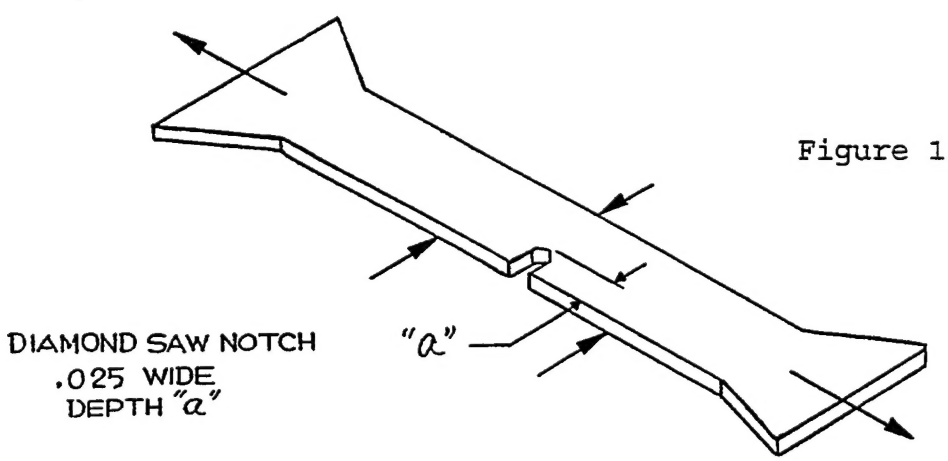

Figure 1

SINGLE EDGE NOTCH (SEN) SAMPLE
IN
THREE POINT BEND

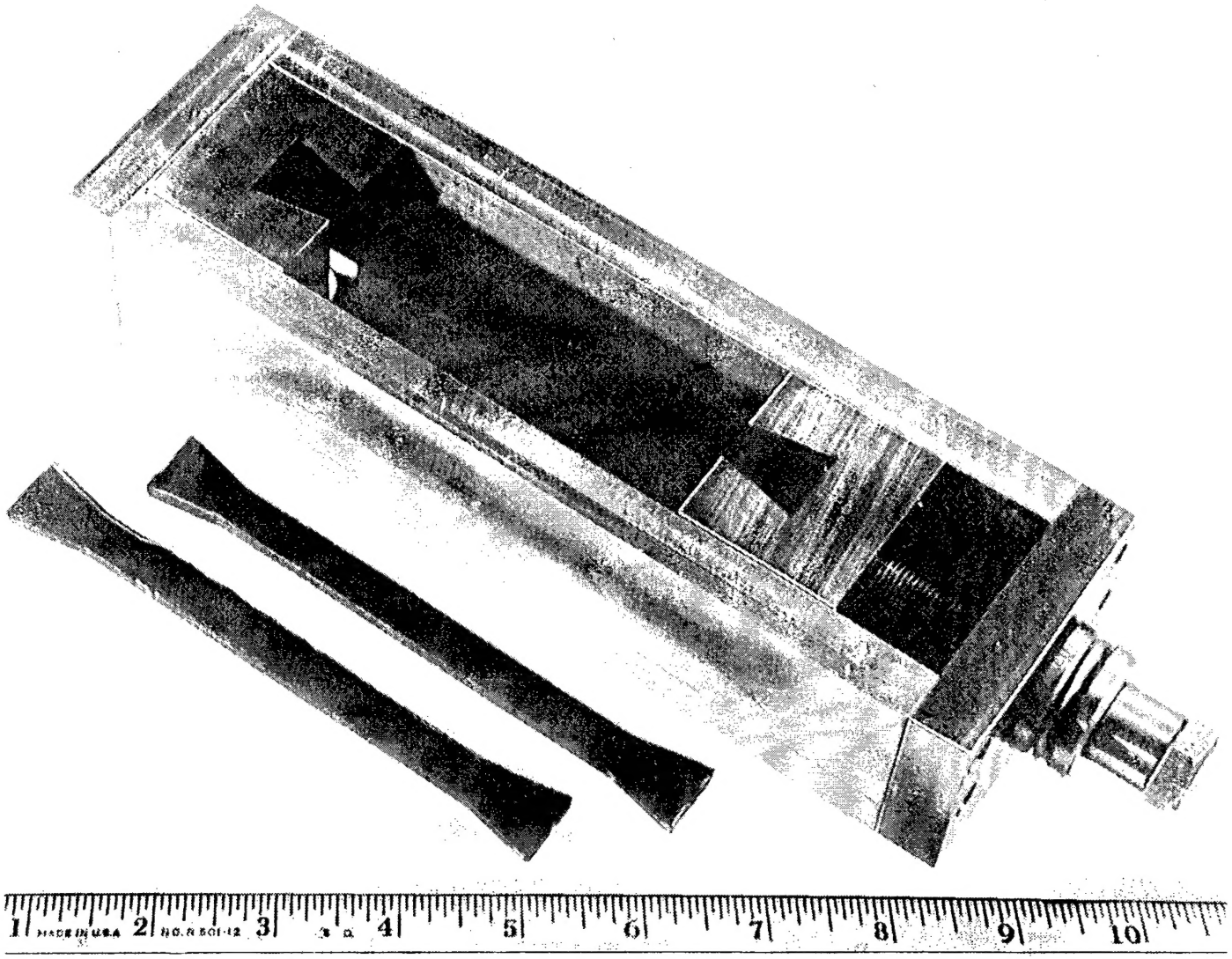

Figure 2 Test Fixture For Measuring Fracture Toughness

THEORY

PER GRIFFITH'S (1920)

$$\sigma_c = \left(\frac{2E\,\gamma_s}{\pi a(1-\nu^2)}\right)^{1/2}$$

σ_c ≡ CRITICAL STRESS (REQUIRED TO INCREASE CRACK LENGTH
E ≡ YOUNG'S MODULUS
γ_s ≡ ENERGY TO MAKE NEW SURFACE
a ≡ SIZE OF CRACK
ν ≡ POISSON'S RATIO

PREDICTS:

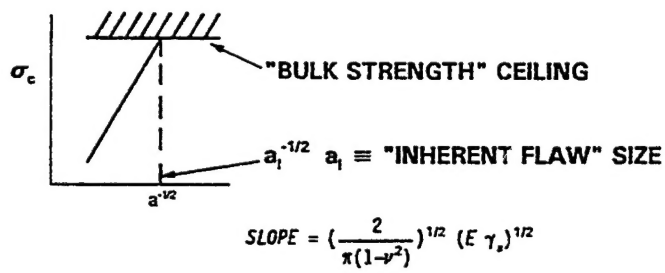

Figure 3 Critical Stress Threshold

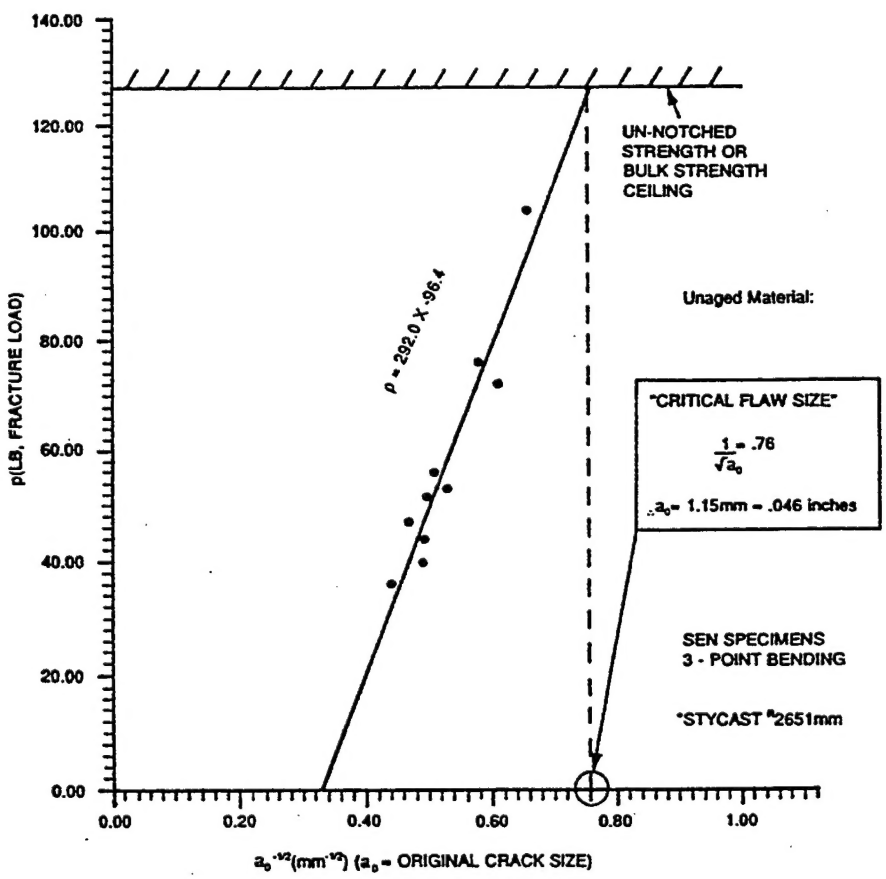

Figure 4 Fracture Load vs. Crack Size

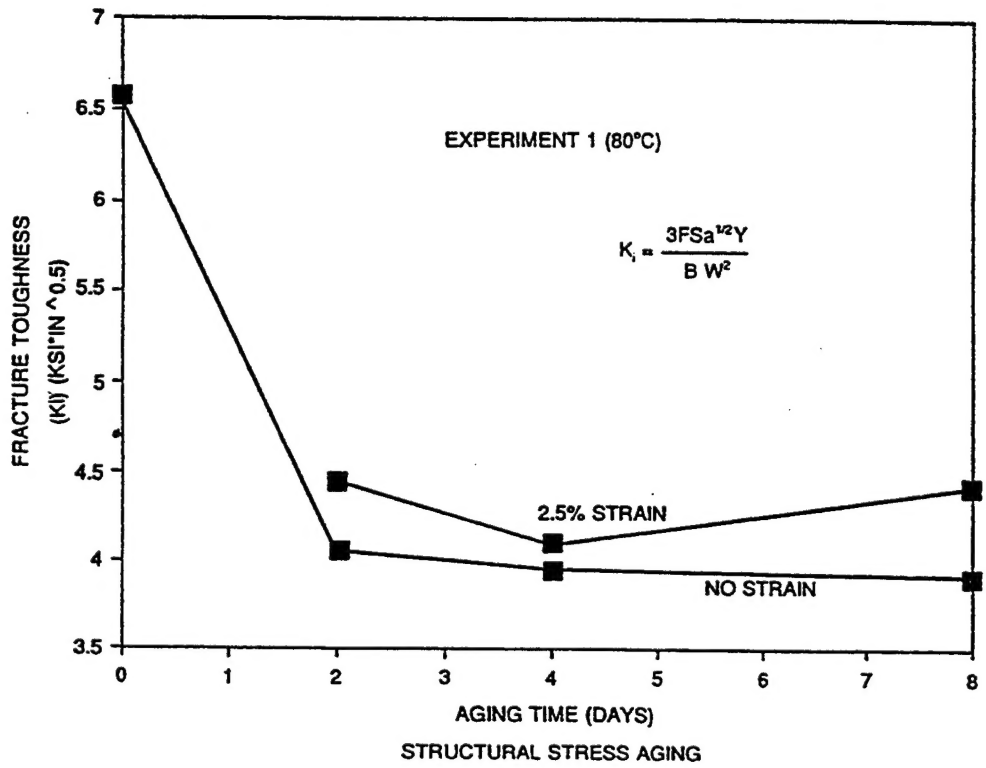

Figure 5 Fracture Toughness vs. Ageing